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# Collaborative Technologies and their Effect on Operator Workload in BMC2 Domains

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Human Effectiveness Directorate
Warfighter Interface Division
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**FOR THE DIRECTOR**

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A primary goal of this project is to understand how introduction of collaborative technologies affects performance and workload associated with C2 tasks. Accomplishing this goal requires multidimensional measurement of workload and analysis of the associations and dissociations that occur between workload and task performance (Matthews, 2001; O'Donnell & Eggemeier, 1986). Each methodology (performance, physiological measurement, and subjective response) offers a separate vista through which the interaction of workload and human performance can be viewed and therefore provide a more comprehensive and accurate assessment. We intend to transfer the techniques and developed methodologies derived for the measurement of the response of the individual to a companion method aimed at providing a comprehensive analysis of the operational context.

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## Table of Contents

## List of Figures

**List of Tables**

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# 1. Introduction

The term *bandwidth* or *throughput*, as used in computing vernacular, expresses the overall physical constraints of a device to process and deliver data. Despite the brain's ability to exquisitely cope with the ubiquity of data supplied through the various sensory channels, it is generally accepted that, as with any information-processing device, the brain is not without its processing limits (Broadbent, 1958). Despite this observation, technology has often been designed to augment biological capacity. For example, the abacus, slide rule, and computer each illustrate technologies that have supplanted humans' natural computation abilities. Indeed, there are ample examples how the emergence of new technologies have improved human cognition.

The miniaturization of digital technology has also permitted the global interconnection of knowledge and real-time exchange of ideas. However, this domain of technological achievement is currently lacking the sophistication for sensitivity to environmentally predefined hierarchical task requirements. Consequently, the result is an environment where technological innovation effectively becomes the prima factor reducing an operators' already limited cognitive capacity. For example, the eco-system of personal digital technologies (e.g., cell phones) exemplifies the many problems posed by task incompatibility (attending to the road whilst toggling the DVD player contained in the dashboard). Similarly, understanding the human factors associated with the novel integration of systems and their collective impact on the capacity limits of the human operator are likely to reduce conditions for error, or stated more simply, as reductions in primary task performance.

The manifestation of capacity limits can be operationalized *as the cognitive workload and stress associated with task performance*. To date, there has been limited theoretical or empirical research to articulate the factors that influence the complete link between performance and

perceived workload. Given that different task domains produce different performance-workload relations, a central question emerges: *what factors drive subjective measures of workload and what information do these measures provide that are not intrinsic to performance measures?* Such relations provide only on single scalar link between multiple faces of performance. Each of these issues are addressed in the present context to better understand how the integration of digital collaborative tools into command and control (C2) environments effect operator mental workload. While it is important to understand the benefits of collaborative tools in C2 domains, the primary purpose of this project was to evaluate the consequences of incorporating collaborative tools as a secondary tasking tool. In the following report, we address the major technical challenges involved in this pursuit, including a summary of relevant research, underlying theoretical framework, and potential implementations to quantify the multidimensionality of workload with specific a locus of interest towards CT in C2 operations.

Network-centricity, as stipulated by the Department of Defense (DOD REFS), has profoundly contributed to the rapid entry of digital technologies into all echelons military life from the dismounted soldier to the battle commander. In his opening paragraph in a report to the United States Congress, Wilson describes the notion of Network-Centric Warfare:

> Network Centric Warfare (NCW) is a key component of DOD planning for transformation of the military. NCW relies on computer processing power and networked communications technology to provide a shared awareness of the battle space for U.S. forces. Proponents say that a shared awareness increases synergy for command and control, resulting in superior decision-making, and the ability to coordinate complex military operations over long distances for an overwhelming war-fighting advantage.

As a result of the DOD's NCW transformation, collaborative technologies (CTs), in particular, have quickly been adopted into critical military operations. Broadly speaking, CT refers to digital platforms to exchange information between two or more people. Such tools as

instant messaging (also called chat), whiteboard, image- and application- sharing, audio- and video- conferencing, as well as file exchange are some examples falling under the rubric of digital collaborative tools. The military's incorporation of CTs are meant to improve operator and team efficiency by serving as a conduit for users to better share, organize, and process information, which may significantly improve operator productivity, decision-making, problem-solving, and team situational awareness.

The DOD's commitment to NCW and reliance of CTs has been reaffirmed in such programs as the Defense Collaboration Tool Suite (DCTS). Accordingly the DCTS, "program provides Combatant Commands (COCOMS), Services, and Defense Agencies, interoperable, real-time, and asynchronous collaboration capability including voice and video conferencing, document and application sharing, instant messaging, and whiteboard capability in support of defense planning." Recently, it was reported that the Royal Australian Navy's Fleet Information Systems Support Organization (FISSO) awarded a contract for development of a collaborative suite supporting United States Special Operations Command (USSOCOM) who have made public requests for technologies that include network-based collaborative tools (Brewin, 2006).

## 1.1 Instant Messaging in the Military

Instant messaging refers to communication through the real-time exchange of digital messages. Digital messaging capabilities have long been a sought after constituent of computing. One of the earliest programs created for digital message exchange called "talk" allowed users to connect to a single user via a command line utility.

In the early evolution of mainstream chat applications the issue of chat message interruptions on primary task performance was considered by Cutrell, Czerwinski, and Horvitz (2000). Participants engaged in a primary web search task and a subsequent design evaluation of

the graphic design quality of a given website. For analysis, Cutrell and colleagues categorized the primary task into three discrete phases. A planning phase where participants were provided with the search target and were asked to construct three search terms prior to continuing with the search and evaluation task. An execution phase where the search terms were entered, and the evaluation phase where participants reviewed the query results. During each phase participants were interrupted with a messaging alert where they were prompted to open the message window, reply, and click an 'OK' button when complete. Messages were counterbalanced such that in some cases they were relevant to the primary task, or alternatively, irrelevant. Cutrell et. al. observed that participants were significantly slower when switching to the instant messaging window during the execution phase of the task (i.e., time from message alert to opening the message window) compared to interruptions occurring in the planning and evaluation phases. Further, a small but significant effect was observed for task completion times, where the evaluation phase took longer to complete compared to the other phases (~ 200 ms). Message completion time as well as the time to resume to the primary task was significantly longer overall for relevant versus irrelevant messages. The study suggests that while message interruptions generally increase task demand, that message interruptions augment certain phases of a task more so than other phases. Whether Cutrell et al's findings have direct applicability to instant message interruptions in command and control, the results do potentially suggest design recommendation in the evolution of intelligent systems which incorporate chat.

The Navy has been one of the first branches of the military to integrate digital collaborative tools into daily operations. Thus, the majority of anecdotal reports or published studies have evaluated the use of collaborative tools germane to Naval operations. In one study, Heacox, Moore, Morrison, and Yturralde (2004) had approximately two hundred respondents

surveyed about their experience using chat. Heacox et al reported that respondents say they use chat 6 to 7 days per week for at least 7 hours per day, that nearly a quarter of respondents monitor 5 or more chat sessions, and that they participate in multiple chat sessions. Heacox et al's report was principally directed at development of chat features that could improve user-interaction with new chat technologies; however, a major question is how these findings impact task performance. While there is an advantage of using chat for rapid communication of information, it is unlikely that interface designers of commercial off the shelf (COTS) products pondered use cases for chat usability issues that could emerge from engaging in chat in this manner. While it is important to consider usability issues of chat clients on their own, an additional tier of evaluation must consider how best to integrate without compromising one's principal duties.

Though CTs are meant to replace outdated systems for information exchange, improve operator efficiency, or to simplify complex collaborative tasks, important questions remain to be answered regarding the performance and workload effects of integrating network-based information sharing tools into contemporary C2 operations. During Operation Iraqi Freedom, for example, instant messaging was used extensively as a means of communication for the Navy fleet (Caterinicchia, 2003). However, anecdotal evidence suggested that a number of unexpected issues developed as a result of this form of communication. Caterinicchia (2003) reported that a military spokesperson addressing the American Society of Navel Engineers' Human Systems Symposium commented that the volume of people simultaneously engaging in chat as a 'nightmare'.

To systematically address problems associated chat communications, Cummings (2004) sought to address both instant messaging interface issues and the consequences of chat on

primary task performance. In her evaluation, Cummings used a Tactical Tomahawk Monitoring and Retargeting Task that required participants to monitor and alter a missile's strike position. During the primary task, participants received instant messages containing either requests for information or status about the current task conditions. Messages were prioritized based on their content. Action messages required participant's to quickly supply information to a superior. Health/Status messages were supplied by the missile and communicated missile position and operational status. Information messages communicated non-critical information. The effect of secondary task demand (i.e., chat) was operationalized using time to reply to message prompts and response accuracy.

The application of CTs into critical C2 operations could arguably be labeled a success recently demonstrated during the Hurricane Katrina disaster. As reported by Moore (2005), the chat feature of the DCTS, supported through the Area Security Operations Command and Control (ASOCC), was heavily used by Naval Emergency Preparedness Liaison Officers (NEPLOs). NEPLOs primary responsibility during the Katrina response was to coordinate with FEMA and other emergency agencies. Moore reported that the chat room hosted as many as 40 simultaneous connections, with approximately 4,500 instant messages exchanged during the response. Early chat capabilities were reportedly well-received:

> The chat tools can help sailors at sea make repairs more quickly when they need to contact technicians on shore for assistance. Using e-mail, phone and other naval message systems have been acceptable methods, but they can cause downtime while technicians wait for an answer. With peer-to-peer technology, personnel at sea and onshore have real-time audio, video and text communication tools to help them find solutions Caterinicchia (2001).

In addition to the DOD sponsored collaborative tools such as the DSTC, a recent adaptation of collaborative tools has begun to permit interoperability among the Army, Navy, and Air Force (Arnone, 2006). The IDM or Inter-Domain Messaging allows for secure

exchanges between these military branches and promotes collaboration and information-sharing for tactical planning and knowledge exchange. Moreover, the US Special Operations Command (USSOCOM) announced their intent in securing collaborative tools for operational planning during the Armed Forces Communications and Electronic Association (AFCEA; Brewin, 2006). Primary and secondary task requirements differentiate chat used in the Katrina disaster versus chat used during Operation Iraqi Freedom. Those users employing chat to communicate during the Katrina recovery efforts arguably were using chat to simply communicate without the burden of another task. However, one would expect different outcomes as a function of using chat in these different domains. While both environments constitute command and control, and both contain elements of stress due to the magnitude of the ongoing situation, it is not surprising that the concatenation of chat for Navel Operators significantly compromised their primary responsibilities.

Applied research has provided significant insight into some of the human integration challenges for realizing the efficient exchange of information via chat when examined in concert with other primary task responsibilities. However, to formally approach the various human factors issues associated with chat, one must also consider the global information processing limitations of the human operator. Therefore, the following section will review those issues closely associated with human information processing constraints, such as attentional allocation, workload, and resource capacity.

## 1.2 Theoretical Considerations

Consistent with theories of selective attention, resource theories postulate a limited capacity information processing system. Thus, the ability to perform a given task is conceptually related to the amount of resources available to meet the demands of that task (Kahneman, 1973;

Norman & Bobrow, 1975). This conjecture does not preclude multiple critical mental operations from occurring concurrently so long as enough resources are available to complete each cognitive action. Resources, in this view, can be conceptualized as a mental fuel that is exhaustible, thereby leading to economic metaphors such as “paying” attention and “investing” effort in tasks.

Advocates of resource theories favor one of two lines of thought. Early resource proponents advanced a single limited capacity resource pool that provides the capacity for mental operations (Kahneman, 1973; Norman & Bobrow, 1975). Kahneman (1973; see Figure 1.1) for example, argued that performance on a task or a group of tasks depended on the amount of resources allocated to each activity.

## 1.3 Mental Workload and Performance

The human brain has evolved in conditions where processing constraints have necessitated neural systems that seek to reduce the burden of a data-rich environment by filtering information through selective attention. The brain must process and organize the voluminous data collected through the sensory systems into a meaningful information array that affords coordination of timely response to novel stimulus contingencies appearing unpredictably in space and asynchronously in time. However, the systems that process this information are inherently limited in their capacities (Broadbent, 1958). These capacity limits are manifested in diverse environments *as the cognitive workload and stress associated with task performance*. To date, there has been limited theoretical or empirical research to articulate the factors that influence the complete link between performance and perceived workload. Given that different task domains produce different performance-workload relations, a central question emerges: *what factors drive subjective measures of workload and what information do these measures*

*provide that are not intrinsic to performance measures?* Such relations provide only on single scalar link between multiple faces of performance.

## 1.4 Resource Theories

Resource theories emerged after the fall of unitary arousal theory (e.g., see Hockey, 1984; Hockey, Gaillard, & Coles, 1986). Consistent with theories of selective attention, resource theories postulate a limited capacity information processing system. Thus, the ability to perform a given task is conceptually related to the amount of *resources* available to meet the demands of that task (Kahneman, 1973; Norman & Bobrow, 1975). This conjecture does not preclude multiple critical mental operations from occurring concurrently so long as enough resources are available to complete each cognitive action. Resources, in this view, can be conceptualized as a mental ‘fuel' that is exhaustible, thereby leading to economic metaphors such as “paying” attention and “investing” effort in tasks.

## 1.5 Single resource views

Advocates of resource theories favor one of two lines of thought. Early resource proponents advanced a single limited capacity resource pool that provides the capacity for mental operations (Kahneman, 1973; Norman & Bobrow, 1975). Kahneman (1973; see Figure 1) for example, argued that performance on a task or a group of tasks depended on the amount of resources allocated to each activity.

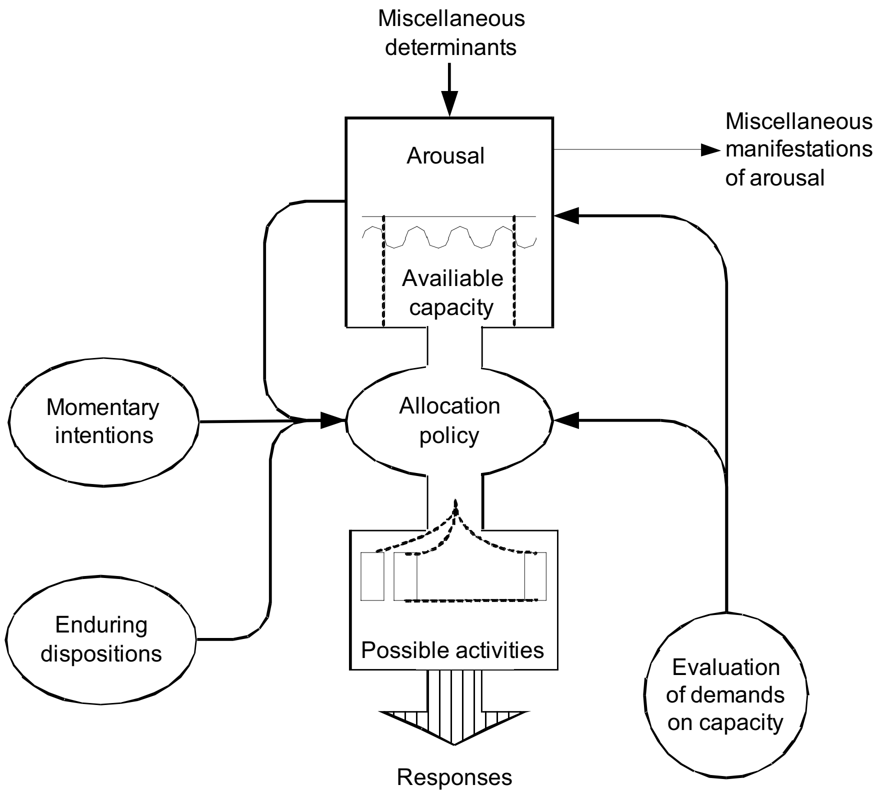


Figure 1.1. *Kahneman's single resource model of attention.*

Although the gross capacity of the single resource pool is fixed its net capacity in part a product of arousal. At center, a resource allocation mechanism determines how much of investment to allot to each of a number of processing activities (at bottom). Such factors as momentary intentions, enduring dispositions, and the determination of capacity demands influenced the allocation of resources for a given task. If resource allocation increases while task demand remains constant, then an increase in performance should result.

## 1.6 Multiple-resource views

In contrast to the view that the brain contains only a single pool of resources, multiple resource theories argue for many independent limited capacity pools that could operate independently (Navon & Gopher, 1979; Wickens, 1984; 2002). Multiple resource theories grew

to accommodate data suggesting that performance of a task in one modality (e.g., a visual task) is virtually unaffected by the addition of a task occupying another modality (e.g., an auditory task).

In the most widely recognized version of multiple resource theory (see Figure 1.2; revised from 1984 model), Wickens (2002) describes a four-dimensional resource model comprised of *processing stages* (perception, cognition, responding), *perceptual modalities* (visual, spatial), *visual channels* (focal, ambient), and *processing codes* (spatial, verbal). This revised version of multiple resource theory evolved from an earlier three-dimensional account (see Wickens, 1984 of a detailed description of each of these dimensions), which did not include a dimension for different visual channels (i.e., focal, ambient).

Both anecdotal (reading a book while walking down a hallway) and experimental (the elucidation of brain structures specific to each type) evidence makes a strong case for disparate resources between these two types of visual processing (Wickens, 2002). Focal vision corresponds to foveal vision for detailed visual processing, while ambient vision refers to peripheral vision. In both variations, Wickens (2002) argues that each element equates to discrete physiological mechanisms establishing its resource independence from other elements. That is, the ability to drive and listen to the radio, read and listen to music, speak and turn on the windshield wipers, can all co-occur to some extent, because performance of each relies upon different resource streams. Critics of multiple resource theory, however, argue that the theory cannot be falsified and that the flexibility afforded by the concept of multiple resources is easily adept to account for new data simply by adding another dimension (Kantowitz, 1987).

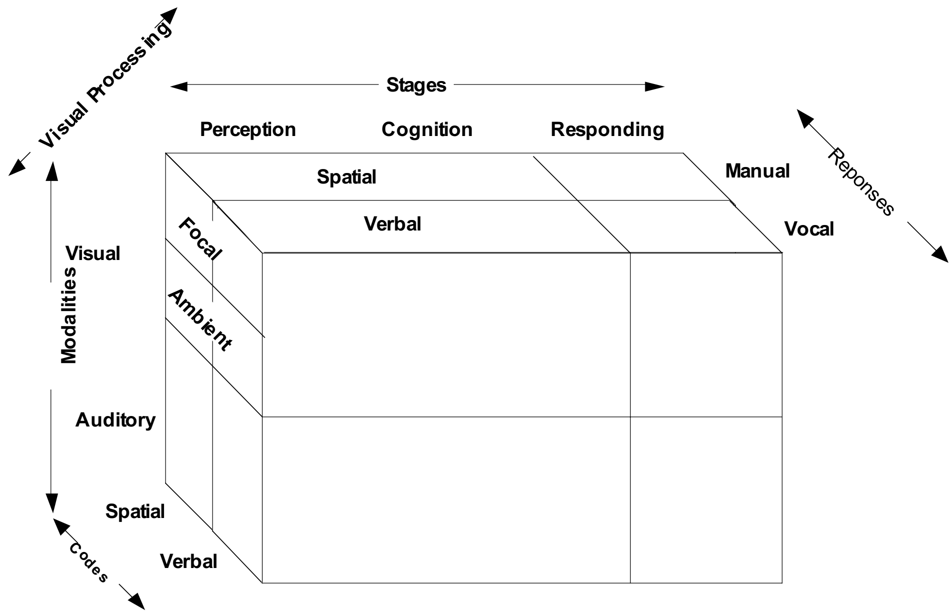


Figure 1.2. *A three-dimensional illustration of Wickens' Multiple Resource Theory.*

## 1.7 Associations-Dissociations of Workload and Performance

Theoretical considerations of human information processing capacity limitations, considered both as energetic and structural limits (e.g., see Szalma & Hancock, 2002), can be utilized for better understanding workload, performance, and the link between them. From the perspective of energetic models of performance, workload can be defined as the difference between operator resources and the cognitive demands imposed by a task or situation (e.g., see Wickens, 1992). Therefore, it is not uncommon for researchers to elucidate a one-to-one mapping between workload and performance for a given task by simply manipulating task demand (Cacioppo, Tassinary, & Bernston, 2000). Researchers who have focused primarily on vigilance tasks, for example, generally report a direct and consistent link between performance and mental workload such that increases in task difficulty simultaneously induce both performance decrements and increased workload (Warm, Dember, Gluckman, & Hancock, 1991; Warm, Dember, & Hancock, 1996; but see also Szalma et al., 2004). However, if a task is

manipulated such that perceived mental workload always parallels performance while decreases in task demand always produce the contrary (i.e., complete association), the diagnosticity of subjective measures of mental workload would have little utility except in circumstances where it is impossible to measure performance itself (see Figure 1.3; Hancock, 1996; Parasuraman & Hancock, 2001; O'Donnell & Eggemeier, 1986; Yeh & Wickens, 1988). Conversely, investigators of multiple-task performance conditions have reported dissociations between perceived workload and performance, indicating that workload is not simply a ubiquitous reflection of task difficulty (e.g., Yeh & Wickens, 1988).

Limited theoretical and empirical research has been conducted to articulate the factors that contribute to performance-workload associations and dissociations. Given that different task domains produce different performance-workload relations, a central question emerges: *What information is provided by subjective measures of workload that is not provided in performance measures?* The description of associations-dissociations in performance as descried by Parasuraman and Hancock (2001) conceptually formalizes an approach to evaluate factors beyond task difficulty that may contribute to explaining the variability in performance.

## 1.8 Subjective Measures of Mental Workload

Subjective measures of mental workload are an important tool that allows easy assessment of the perceived task demands placed upon an operator. Numerous psychometric tools used to assess mental workload have been developed in the past several decades. The currently dominant measures of perceived workload are the NASA-TLX (Task Load Index; Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT; Reid & Nygren, 1988). The NASA-TLX and SWAT are multidimensional scales of workload. The NASA-TLX, for instance, produces a global workload score by computing a weighted average of

ratings on the following six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration

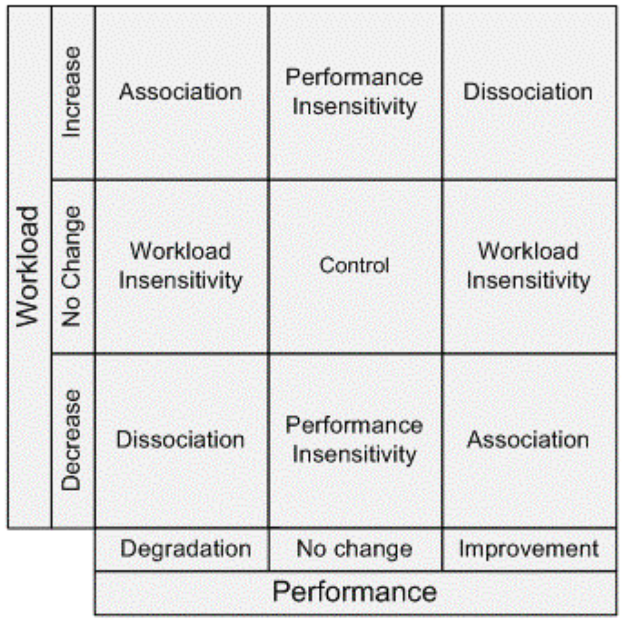


Figure 1.3 *Matrix of performance and workload association and dissociations adapted from Parasuraman, R. & Hancock, P.A. (2001). Adaptive control of mental workload. In: P.A. Hancock and P.A. Desmond (Eds.) Stress, workload and fatigue, (pp.308) Erlbaum: Mahwah, NJ.*

## 1.9 Psychophysiological Measures of Mental Workload

While subjective measures have many advantages they represent but one output system (subjective and verbal report) to quantify the substrata that compose the multidimensionality of workload. Applying a three-systems approach to understand workload (see Lang, 1993), physiological function may provide critical information not accessible or not readily assessed through other means. Psychologist and neuroscientist alike, for example, have mutually benefited with the advent of neuroelectric assessment and blood oxygen imaging techniques. Nevertheless, technological innovation is no substitute for weak experimental design. In the context of understanding the complexity of human-machine systems, it is sometimes impractical to incorporate physiological instrumentation as a result of unreasonable signal-to-noise

compromises, logistical difficulties, or obtrusiveness with primary task demands (Kramer & Weber, 2000). Nevertheless, as with any task, the ability to assess multiple levels of analysis has its benefits, specifically when assessing constructs that may be difficult to measure with conventional methods.

### 1.9.1 Event Related Potentials

Psychophysiological measures have been successfully used to investigate a number of issues as they pertain the human mental workload (Parasuraman, 1990). ERPs refer to a broad class of waveforms that occur specifically in response to actual or anticipated stimuli (Andreassi, 2000). ERP's are extracted by timelocking the raw electrocortical activity to some temporal event. ERPs differ from frequency derived EEG data in that, the latter provides spectral specific information. The term ERP encapsulates a large set of time-locked cortically derived measures, for example, long-latency potentials, sensory ERPs (auditory, visual, somatosensory), and steady-potential shifts (contingent negative variation, readiness potentials, far-field potentials), each varying in their latency and response characteristics. Because of signal-to-noise issues, ERPs are quite small, and therefore multiple trials are generally averaged to remove the background EEG activity not time-locked to the stimulus or event. Once completed, waveform summary statistics can be isolated by extracting peak amplitude (positive or negative) and peak latency (see Fabiani et al., 2000, Picton et al., 2000).

ERPs have been used extensively to examine human information processing, with latency and amplitude response characteristics thought to vary with the attentional requirements of a task (for a comprehensive review, see Birbaumer et al., 1990; Hillyard & Hansen, 1986). For example, both the N1 and P3 components of the cortical event-related potential (ERP) have been used to evaluate mental workload, and attention in general. For the P3 (i.e., the positive

deflection that occurs at approximately 300 ms), a typical monotonic relationship is often identified. That is, as workload increases, ERP amplitude evoked in response to a secondary task is attenuated (e.g., Kramer, Wickens, & Donchin, 1985). Because ERPs appear to index the capacity limitations predicted by resource models, they provide a unique means to assess workload at the earliest stages of information processing.

### 1.9.2 Brain Imaging Techniques

Unlike EEG that has excellent temporal but poor spatial resolution, both positron emission tomography (PET), and functional magnetic resonance imaging have good spatial resolution but poor temporal resolution. However, both of these techniques have been used extensively to isolate those brain areas whose activation is coincident with human information processing. Gruber and colleagues (Gruber, Müller, Keil, & Elbert, 1999), for example, found that cerebral blood flow (via PET) increases in specific brain areas when an individual attends to a specific stimulus, or shifts spatial attention to visual stimuli in varying visual fields. PET evidence has indicated that the superior parietal and superior frontal cortex activate when attention shifts to peripheral locations compared to when attention gaze is fixated at a center location (Corbetta, Miezin, Shulman, & Peterson 1993). Similarly, fMRI evidence indicates that blood oxygenation in specific cortical regions increases when participants attend to dynamic stimuli as compared to when this stimuli is ignored (Baauchamp, Cox, & DeYoe, 1997; Haug, Baudewig, & Paulus, 1998). It may be assumed that attention results in a salient magnification of neuronal activity in cortical regions or pathways that are associated with the demands that are required to process the attended stimulus (Hillyard, Vogel, & Luck, 1998).

### 1.9.3 Heart Rate Variability

Like brain measurement techniques, measures of heart rate variability (HRV) have been used extensively as a physiological metric for mental workload (Nickel, Friedhelm, & Ossietzky, 2003). Variability of the heart signal refers primarily to the variance associated with the interbeat interval as indicated by each R-wave peak, although different electrocardiographic (ECG) components are also employed for performing medical diagnoses. Once parsed from the raw ECG, interbeat intervals are commonly subjected to a Fourier transformation to obtain the spectral power in different frequency ranges. For workload, what is termed the low frequency band, which reflects spectral power in the 0.04 to 0.15 Hz range (LFB) and the high frequency band 0.15 to 0.4, has received the greatest interest because these range appears most sensitive to manipulations of stress and workload (Appelhans & Luecken, 2006). The sensitivity of the LFB and HFB ranges to task induced stress is partially a result of vagus nerve innervation by parasympathetic and sympathetic inputs. The right vagus projects to the heart's sinoatrial node, which serves as the heart's pacemaker. Innervation of the sinoatrial node produces a decrease in heart rate (i.e., parasympathetic input). The sinoatrial node also receives afferent input from the sympathetic system via spinal nerves. The spectral variability is a product of the slow acting norepinephrine from sympathetic inputs versus acetylcholine inputs via the parasympathetic system (Appelhans & Luecken, 2006). Spectral power in the low frequency band would therefore indicate sympathetic influences, while power in the high frequency band would indicate parasympathetic influences.

### 1.9.4 Pupillometry and Eye Tracking

Measurement of pupillary changes as a function of task load has been a longstanding tool for exploring numerous psychological and cognitive processes (Andreassi, 2000; Janisse, 1977). Such measures have been used in the study of cognitive effort and information processing

extensively, where it is typical to observe increases in pupil dilation as a function of processing load (Beatty, 1982; Granholm, Asarnow, Sarkin, & Dykes, 1996; Hyönä, Tommola, & Alaja, 1995). Despite its many uses, however, evaluation of pupillary changes to complex visual stimuli presents the problem of effectively parsing psychological modulation from core pupillary function. For instance, the light reflex (i.e., regulating the amount of light that enters the eye) and accommodation response (i.e., changing the curvature of the lens to control depth of field), among others (see Tyron, 1975), are two such sources of variation that potentially may confound response measurements. Bradley (2000) has addressed this issue when assessing cardiac function in emotion, where the primary "homeostatic and metabolic (p. 624)" needs of the body can mask affective influence. The use of the pupil is another such measure that can easily be confounded in this regard, yet, its sensitivity to task demands merits its role in the psychophysiological study of workload if these factors are considered. In addition to both ERPs and pupillary function, eye-tracking can provide important information regarding the allocation of attention in real time.

Eye tracking can provide important insight regarding the level of workload by revealing how an operator interacts with his/her environment through visual information extraction strategies (Kramer & Weber, 2000). Seagull et al. (1999), for example, developed a resource model of monitoring, where the human operator builds knowledge representations about their environment. The pattern of monitoring, however, changes depending on the level of operator workload. That is, as workload increases monitoring behaviors decrease. Beyond monitoring behavior, identifying strategy shifts are an important marker of workload because they reflect the amount of cognitive effort that an operator gives to a task. By evaluating eye movement metrics during collaborative task performance, we may also be able to elucidate operator strategy shifts that may not be observable through other means (Marshall, Pearce, Dickson, 2002).

## 1.10 Summary

A primary goal of the proposed project is to understand how introduction of collaborative technologies affects performance and workload associated with $C^2$ tasks. Accomplishing this goal requires multidimensional measurement of workload and analysis of the associations and dissociations that occur between workload and task performance (Matthews, 2001; O'Donnell & Eggemeier, 1986). To this end, we have proposed a multi-modal assessment bridging subjective, behavioral, and physiological levels of analysis to provide a comprehensive account of workload and performance. Each methodology (performance, physiological measurement, and subjective response) offers a separate vista through which the interaction of workload and human performance can be viewed and therefore provide a more comprehensive and accurate assessment. We intend to transfer the techniques and developed methodologies derived for the measurement of the response of the individual to a companion method aimed at providing a comprehensive analysis of the operational context. Success in these efforts will be central to any success of an overall program to provide training and simulation-based support to modern soldiers.

# 2. Method

## 2.1 Participants

Participants included 26 students from the University of Central Florida who were recruited from undergraduate courses in exchange for a small amount of extra course credit. Of those participants, 11 were Male and 15 were Female, with an average age of 21.67 years (SD = 6.17). Most participants described themselves as Caucasian (n = 18). Other racial groups represented in the sample included African-American (n = 3), Hispanic (n = 4), and Asian (n = 1). The majority of participants were Freshman (n = 15), followed by Seniors (n = 6),

Sophomores (n = 3), and Juniors (n = 2). Because of experimenter, computer, or other technical problems, the final samples sizes were the following for each dependent variable: *DDD Performance data* (*n* = 22), Heart Rate Variability (*n* = 23), *Self-Reported Workload* (*n* = 21), ERPs (*n* = 10), *Secondary Task Performance* (*n* = 19).

## 2.2 Materials

Perceived mental workload was measured by the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988). The NASA-TLX is an instrument that gauges six dimensions of perceived workload on a scale of 0 to 100. A computerized version of the NASA-TLX was created for the experiment. This version was written in LabVIEW 8.0 and presented the various NASA-TLX dimensions (i.e., Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration) to participants using customized sliders. The computerized version also presented all possible pairwise comparisons randomized for each participant.

In all experiments mood states was measured using the Dundee State Questionnaire (DSQ), which is a multidimensional instrument for assessing transient states associated with mood, arousal and fatigue (Matthews et al., 1999). This instrument has been shown to be sensitive in investigating the effects of task factors on operator mood state that can potentially contribute to task demands (Grier, et al., 2004; Helton, Dember, Warm, & Matthews, 1999; Matthews, et al., 1999; Szalma et al., 2004).

Both state and trait anxiety were assessed using the STAI (State-Trait Anxiety Inventory, Spielberger et al., 1983*).* Each dimension of the STAI (i.e., state and trait) consists of a 20-item questionnaire, which ask respondents to indicate how they feel about a particular statement using a 4-point scale anchored at the extremes with 1 (almost never) to 4 (almost always). High scores reflect greater state/trait anxiety. STAI scores have demonstrated sound psychometric properties,

including inter-item consistency, predictive validity, differential stability for trait anxiety (i.e., test-retest reliability ~ .75), and divergent validity (Spielberger et al., 1983).

## 2.3 Apparatus

The experiment's synthetic task environment (STE) was a command and control task developed for use with the Dynamic Distributed Decision-Making Testbed (DDD; Aptima, Inc.). The DDD is a software application that serves as a platform for designing uni- and multi-player task scenarios. These task scenarios can be created such that they mimic certain characteristics common to real-world command and control domains.

The experiment used the 'Tanker Scenario' provided by our AFRL research partner that was subsequently modified for use with a single operator. In the modified version, the participant serves the dual role of Battle Commander and the Strike Operator. The scenario requires the operator manage a number of air (Refueling Tanker, Jet Fighter) and ground assets (Base). Management in this capacity requires that the operator protect assets by coordinating attacks against enemies, refueling jet fighters, and launching new aircraft when necessary. The 'Tanker Scenario' allows the operator to view the entire battle space.

The DDD testbed is presently designed for use with Linux (Red Hat 9, Fedora Core 4). Because the secondary task required integration of instrumentation that could only run in a Microsoft Windows environment, the following testing environment was assembled. First, Parallels Virtual Machine was used as a hypervisor to host the Linux operating system (OS) within Microsoft Windows XP. Figure 2.1 shows an example of this virtualization on using Apple OSX as the host operating system platform and shows RedHat 9 Linux and Microsoft Windows XP guest OS's operating concurrently within this host. This configuration offers a great degree of flexibility given that multiple RedHat OS's can be cloned and configured across

multiple computers. Figure 2.2 depicts a screenshot of the actual experimental window. The image appears smaller because the screenshot spans two monitors. The left side of the figure shows the DDD task window running in Linux The right side of the figure displays the physiological data collection software running in Windows.

The Laboratory testbed used three monitors, two for the experimenter and the other for the participant. A Belkin monitor replicator was used to duplicate the Linux window for view both by the participant and experimenter, while the experimenter used the other monitor display the physiological software. The Linux window was recorded for the each condition using Camtasia Software (Techsmith).

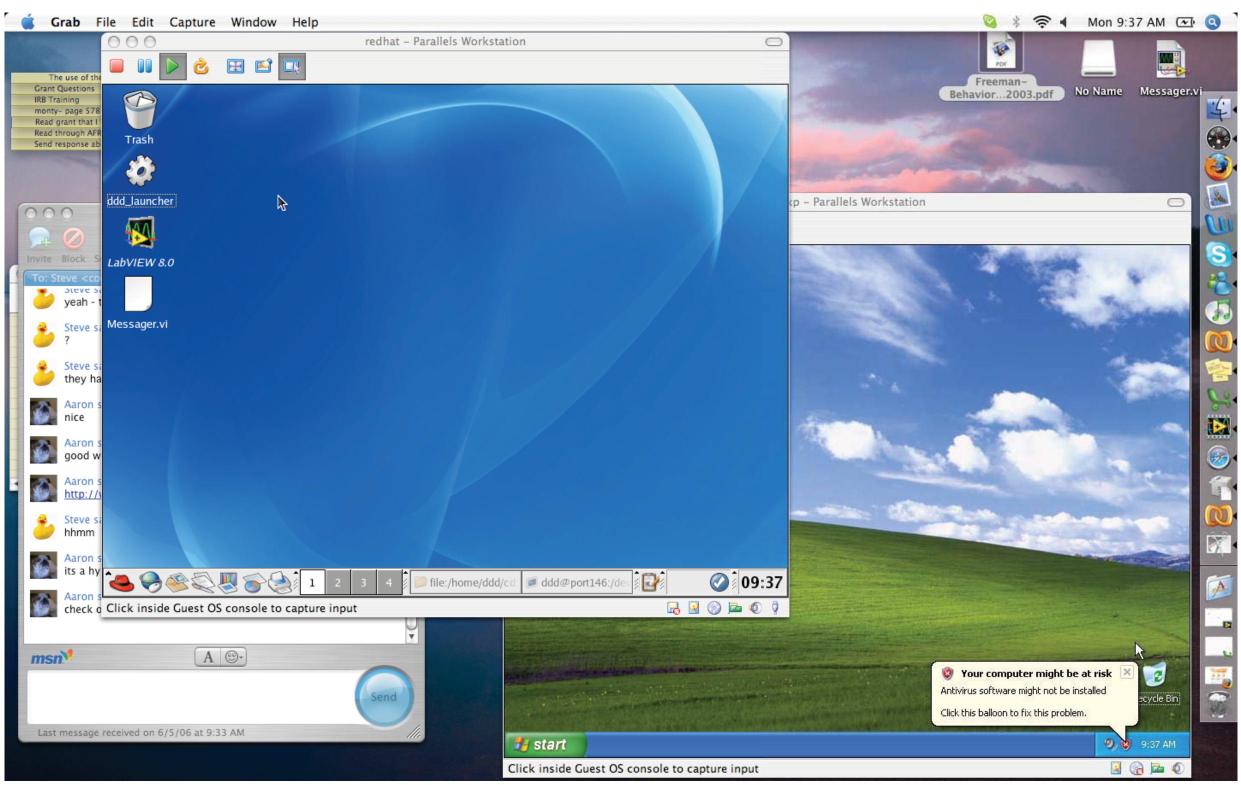


*Figure 2.1. Example of the virtualization environment showing an Apple OSX host operating system, running two guest operating systems (RedHat Linux 9 on the left and Microsoft Windows XP on the Right).*

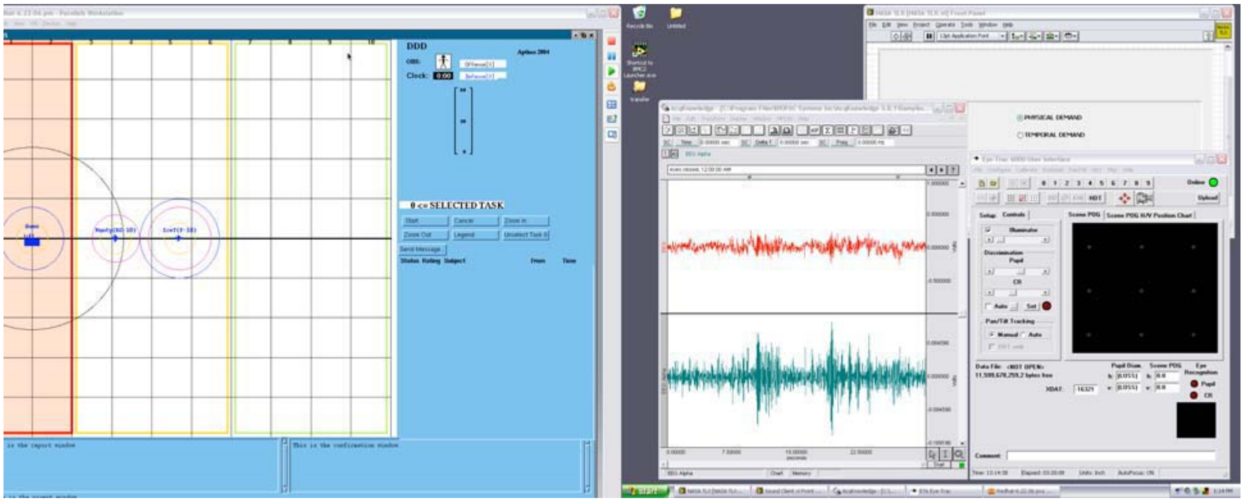

*Figure 2.2. Screenshot shows the experimenter operating views. The DDD testbed (shown on the right) was recorded by screen capturing software and duplicated to the participant on another monitor. The right half of the image shows the physiological data collection software and the digital version of the NASA-TLX.*

## 2.4 Physiological Data Collection

All physiological measures were collected using Acknowledge software (3.7.8, Biopac Systems, Inc., Santa Barbara, CA) that was used to interface an MP150 control module (12-bit A/D converter; Biopac Systems, Inc). All signals were sampled at 1 kHz for the entire length of each task condition. Electrocardiographic (ECG) measurement was collected using Ag/AgCl electrode leads placed on the left and right middle deltoid. Raw ECG signals were analog filtered with a passband of 0.05 to 35 Hz and amplified 5000 times. Electroencephalographic (EEG) activity was assessed at three Parietal sites (P3, PZ, P4) via an electrode (Sn) cap (Electro-cap International) with placement specified by the International 10-20 System (Jasper, 1958). Raw EEG signals were filtered with a passband of 0.01 to 35 Hz and amplified 50,000 times. All channels were referenced to a physically linked ears reference configuration using two tin electrodes positioned on the lobule of the left and right ear. To correct for ocular artifacts, vertical and horizontal eye movement was monitored via an electroocculogram bioamplifier

(EOG) using Ag/AgCl electrodes. Horizontal eye movement was recorded at the left and right outer canthi, and vertical eye movements were recorded from positions above and below the eye. Figure 2.3 illustrates the testbed setup. The inclusion of the eyetracker is illustrated for possible inclusion for additional experimentation.

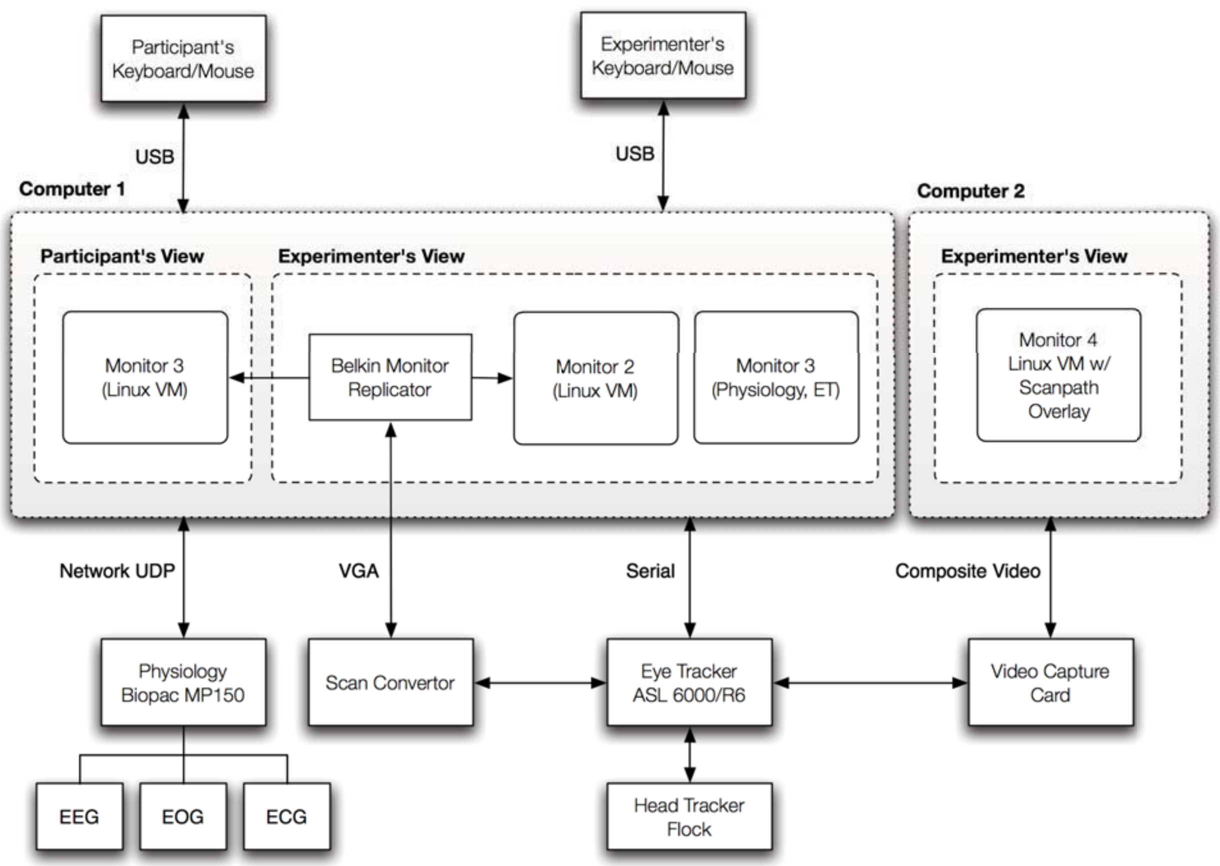


*Figure 2.3. Diagram illustrates the hardware and software configuration for the assembled testbed.*

## 2.5 Data Reduction

Dependent measures for heart rate variability were obtained using the following method. Following artifact removal, R-R intervals (Interbeat Interval – IBI) were extracted from the filtered and amplified ECG signal. To extract spectral components, these values were then

subjected to Fast Fourier Transformation. Once complete, peak power in the following spectrums indices were derived as gross dependent measures of sympathetic activation: Very Low Frequency Band (VLFB) 0 to 0.04 Hz; Low Frequency Band (LFB) 0.04 to 0.15 Hz, High Frequency Band (HFB)

To isolate dependent measures derived from EEG recordings, event-related potentials (ERP) were derived by averaging EEG activity 100 ms prior and 500 ms following the onset of time-locked to the onset of the tone. Once averaged, the ERP was baseline corrected by subtracting a computed average of the 100 ms EEG activity from the pre-tone baseline from each subsequent point in the waveform. For the dependent measures of interest, the peak amplitude and latency of the N1 and P3 was used as the summary statistics for later analyses.

## 2.6 Procedure

Participants visited the lab on two separate occasions. On the first visit, participants were required to read and sign a University approved informed consent form (see Appendix A). Participants were then asked to complete the STAI-Trait, the EPQ, and a short demographic questionnaire. Once complete, participants were presented with the DDD training materials (see Appendix B). The training materials were presented in an instructor-lead format, where the basic operation of the DDD and some details of the 'Tanker Scenario' were provided. These details included such information as the participant's function in the DDD STE, their primary mission objectives, and scenario rules. Participants were also instructed that they would be relaying latitude and longitude coordinates via an instant messaging interface at various points during the experiment. Once final questions about the DDD STE were addressed, participants then completed the NASA-TLX. This was to familiarize participants with the instrument prior to the experimental session. The participants then had an opportunity to use the DDD in a simple task

scenario. The scenario was a modified 'Tanker Scenario', where a single base, tanker, and jet fighter served as the primary assets. Participants were required to qualify for the study by completing the following objectives: (1) Pursue an enemy, (2) Destroy an enemy, (3) Orbit an aircraft, (4) Launch an aircraft from the base, (5) Refuel at the tanker. Participants were then scheduled for the experimental session. The first session took approximately 1 hour and 30 minutes to complete. The second visit consisted of the experimental session. Participants were asked to first complete the STAI-State and the DSSQ pre-task questionnaire. The electrodes were then affixed. The experiment exposed participants to two task Scenarios consisting of (Easy, Difficult) by Message (One Latitude/Longitude Coordinate, Three Latitude/Longitude Coordinates) combinations co (i.e., four total conditions) in a counterbalanced arrangement

## 3. Results

While no a priori hypothesis were made regarding performance differences between gender, preliminary evaluation of the data indicated that a potential confound existed when collapsing results across gender. While workload hypothesis related to Gender differences as operators engage in collaborative dual-tasking was not the intended emphasis of this investigation, results will be presented such that Gender will be introduced as a factor to isolate the variance attributed to this variable.

### 3.1 DDD Performance Data

Because preliminary examination of the data indicated empirical differences with respect to primary task performance and gender, primary task performance was evaluated using a Multivariate Analysis of Variance (MANOVA) across the primary/secondary factor combinations (Easy/One Message, Easy/Three Message, Difficult/One Message, Difficult/Three Message). This combination yielded a Gender (Male, Female) x Primary Task Difficulty (Easy,

Hard) x Message Length (One Message, Three Messages) with repeated measures on the last two factors. The following dependent variables were included in the analysis: *Total Enemies Destroyed, Total Attacks in Green, Yellow, and Red Zone, Total Fighters Lost, Total Enemies to Enter the Green, Yellow, or Red Zone, the total time in the Green, Yellow, and Red Zone, Total Correct Refuels, Total Incorrect Refuels, Time From Target Identification to Target Elimination, and Aircraft Lost to Fuel.*

The omnibus multivariate interaction for Gender x Primary Task Difficulty x Message Length only approached significance, F (15, 6) = 3.49, λ = 0.103, p = .066. Although not statistically significant, this interaction was further examined given the strong linear trend and the exploratory nature of this experiment. Follow-up univariate Analysis of Variance (ANOVA) tests were subsequently considered to further isolate those dependent variables contributing to the interaction. Both *Total Fighters Lost* and *Total Aircraft Lost to Fuel* were significant, $F$ (1, 20) = 5.57, $p < .05$ and $F$ (1, 20) = 4.80, $p < .05$, respectively. A strong linear trend was observed for the *Total Enemies to Enter the Yellow Zone,* $F$ (1, 20) = 3.10, $p = .09$. Table 3.1 presents the means for each of these dependent variables. Post hoc analyses were only considered for *Total Fighters Lost* and *Total Aircraft Lost to Fuel*.

*Table 3.1. Gender x Primary Task Difficulty x Message Cell Means*

| | | | Fighters Lost | | Aircaft Lost Fuel | | Enter Yellow | |
|---|---|---|---|---|---|---|---|---|
| **Gender** | **Primary Task** | **Messages** | **Mean** | **Std. Error** | **Mean** | **SE** | **Mean** | **SE** |
| **Male** | **Easy** | **One** | 0.000 | 0.286 | 0.222 | 0.234 | 0.222 | 0.209 |
| | | **Three** | 0.111 | 0.120 | 0.556 | 0.203 | 0.222 | 0.274 |
| | **Difficult** | **One** | 0.556 | 0.447 | 0.556 | 0.229 | 0.778 | 0.438 |
| | | **Three** | 2.444 | 0.594 | 0.444 | 0.247 | 2.000 | 0.521 |
| **Female** | **Easy** | **One** | 0.308 | 0.238 | 0.769 | 0.195 | 0.769 | 0.174 |
| | | **Three** | 0.154 | 0.100 | 0.538 | 0.169 | 1.000 | 0.228 |
| | **Difficult** | **One** | 1.846 | 0.372 | 0.538 | 0.191 | 2.923 | 0.364 |
| | | **Three** | 1.538 | 0.494 | 0.692 | 0.206 | 3.308 | 0.433 |

In addition to the three-way interaction, a two-way interaction for the Gender x Primary Task Difficulty MANOVA emerged, $F$ (15, 6) = 3.97, $\lambda$ = 0.092, $p$ < .05. This interaction was also subsequently parsed via univariate ANOVAs for each dependent variable. Only *Total Enemies to Enter Yellow Zone* was significant, $F$ (1, 20) = 5.62, $p$ < .05.

*Table 3.2. Gender x Primary Task Difficulty*

| | Enter Yellow | | |
|---|---|---|---|
| **Gender** | **Primary Task** | **Mean** | **SE** |
| **Male** | **Easy** | 0.222 | 0.199 |
| | **Difficult** | 1.389 | 0.421 |
| **Female** | **Easy** | 0.885 | 0.166 |
| | **Difficult** | 3.115 | 0.351 |

A main effect for Primary Task Difficulty was also observed, $F$ (15, 6) = 316.163, $\lambda$ = 0.001, $p$ < .001. With the exception of the *Number of Attacks in the Red Zone, Enemy Time in the Red Zone, Correct Refuels, Incorrect Refuels*, all other univariate tests were significant confirming that manipulation of primary task difficulty was successful (see Table 3.2). Although, it should also be noted that some dependent variables are loaded with both the manipulation of task difficulty as well as participant performance. For example, the *Number of Enemies Destroyed* is highly significant between the two task conditions because manipulation of task difficulty was obtained by increasing the number of enemy assets that the participant had to engage. This information is conflated with performance data, therefore, making it difficult to parse which variance is solely a function of the task manipulation and which indicates how a participant performed under the different task constraints.

*Table 3.3. Univariate tests for the Main Effect Task Difficulty*

| | Statistic | | | Condition | | | |
|---|---|---|---|---|---|---|---|
| | | | | Easy | | Difficult | |
| **Dependent Measure** | **Test** | ***F*** | ***p*** | **Mean** | **SE** | **Mean** | **SE** |
| **Enemies Destroyed*** | F (1, 20) = 322.198 | 322.198 | 0.000 | 4.408 | 0.278 | 9.989 | 0.329 |
| **Attack Green*** | F (1, 20) = 108.207 | 108.207 | 0.000 | 3.998 | 0.366 | 8.344 | 0.494 |
| **Attack Yellow*** | F (1, 20) = 26.393 | 26.393 | 0.000 | 0.391 | 0.114 | 1.795 | 0.318 |
| **Attack Red** | F (1, 20) = 0.215 | 0.215 | 0.648 | 0.038 | 0.032 | 0.019 | 0.023 |
| **Fighters Lost*** | F (1, 20) = 35.289 | 35.289 | 0.000 | 0.143 | 0.097 | 1.596 | 0.260 |
| **Enter Green*** | F (1, 20) = 454.881 | 454.881 | 0.000 | 5.250 | 0.272 | 11.444 | 0.216 |
| **Enter Yellow*** | F (1, 20) = 57.618 | 57.618 | 0.000 | 0.553 | 0.129 | 2.252 | 0.274 |
| **Enter Red** | F (1, 20) = 2.029 | 2.029 | 0.170 | 0.066 | 0.039 | 0.229 | 0.115 |
| **Time Green*** | F (1, 20) = 10.356 | 10.356 | 0.004 | 98.531 | 5.630 | 111.856 | 3.620 |
| **Time Yellow*** | F (1, 20) = 12.107 | 12.107 | 0.002 | 26.726 | 7.946 | 51.870 | 7.219 |
| **Time Red** | F (1, 20) = 1.751 | 1.751 | 0.201 | 3.216 | 1.893 | 20.622 | 12.894 |
| **Correct Refuels** | F (1, 20) = 3.59 | 3.590 | 0.073 | 1.573 | 0.128 | 1.276 | 0.209 |
| **Incorrect Refuels** | F (1, 20) = 0.191 | 0.191 | 0.667 | 0.075 | 0.051 | 0.103 | 0.054 |
| **Identify To Destroy Time*** | F (1, 20) = 22.072 | 22.072 | 0.000 | 121.850 | 8.818 | 163.991 | 7.537 |
| **Aircraft Lost Fuel** | F (1, 20) = 0.048 | 0.048 | 0.828 | 0.521 | 0.124 | 0.558 | 0.133 |

The multivariate MANOVAs for the Gender, $F$ (15, 6) = 1.261, $\lambda$ = 0.241, and Message main effect, $F$ (15, 6) = 1.397, $\lambda$ = 0.223, were not significant. Also, the Gender x Message or the Primary Task Difficulty x Message interactions were also not significant, $F$ (15, 6) = 0.681, $\lambda$ = 0.370 and $F$ (15, 6) = 0.832, $\lambda$ = 1.261, respectively.

## 3.2 Self-Report Workload

Self-reported workload assessed using the NASA-TLX was evaluated using a Gender (Male, Female) x Primary Task Difficulty (Easy, Hard) x Message Length (1 Message, 3 Messages) with repeated measures on the last two factors MANOVA that included each of the instruments five workload subscales (i.e., Mental, Physical, Temporal, Performance, Effort, Frustration). Table 3.4 reports the means and standard errors for each of the observed factos combinations. No higher or lower order interactions were identified as significant for self-reported workload on the TLX; Gender x Primary Task Difficulty x Message Length, $F$ (6, 14) = 1.733, $\lambda$ = 0.568; Gender x Primary Task Difficulty, $F$ (6, 14) = 0.506, $\lambda$ = 0.822; Gender x

Message Length, $F$ (6, 14) = 0.868, $\lambda$ = 0.729. However, the main effect for Primary Task Difficulty was significant, $F$ (6, 14) = 3.288, $\lambda$ = 0.415, $p < .05$ providing initial evidence that the manipulation was successful in sufficiently varying workload between the two tasks when collapsed across the Message Length. A strong linear trend for the Message Length main effect was also observed, $F$ (6, 14) = 2.433, $\lambda$ = 0.490, $p = .08$.

*Table 3.4. Means and standard errors for the weighted NASA-TLX dimensions and factor combination.*

| | | | Mental | | Temporal | | Performance | | Effort | | Frustration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | **Primary Task** | **Message** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** |
| **Male** | **Easy** | **One** | 1.69 | 0.43 | 1.37 | 0.42 | 1.16 | 0.38 | 1.12 | 0.32 | 0.47 | 0.37 |
| | | **Three** | 1.62 | 0.40 | 1.03 | 0.41 | 0.78 | 0.25 | 1.30 | 0.38 | 0.58 | 0.42 |
| | **Difficult** | **One** | 1.66 | 0.42 | 1.85 | 0.41 | 0.95 | 0.33 | 1.24 | 0.32 | 0.52 | 0.52 |
| | | **Three** | 2.32 | 0.53 | 2.12 | 0.42 | 0.84 | 0.28 | 1.79 | 0.34 | 1.10 | 0.48 |
| **Female** | **Easy** | **One** | 2.11 | 0.37 | 1.74 | 0.36 | 0.86 | 0.33 | 1.32 | 0.28 | 0.56 | 0.32 |
| | | **Three** | 2.08 | 0.35 | 1.57 | 0.35 | 0.96 | 0.22 | 1.61 | 0.33 | 0.75 | 0.36 |
| | **Difficult** | **One** | 2.44 | 0.36 | 2.32 | 0.35 | 1.04 | 0.29 | 1.24 | 0.28 | 1.59 | 0.45 |
| | | **Three** | 2.91 | 0.46 | 2.03 | 0.37 | 1.09 | 0.24 | 1.81 | 0.30 | 1.03 | 0.41 |

* Note that the Physical Workload dimension has been removed for presentation and that values represent weighted TLX scores / 100.

The univariate ANOVAs were subsequently considered to evaluate which of the TLX subscales contributed to either of the multivariate main effects. For Primary Task Difficulty, both the Mental and Temporal workload dimensions were significant, $F$ (1, 19) = 7.231, $p < .02$ and $F$ (1, 19) = 6.761, $p < .02$, respectively. Thus, mental workload significantly increased from ($M$ = 1.873, $SE$ = 0.26) for the *Easy Primary Task* condition to ($M$ = 2.333, $SE$ = 0.304) for the *Difficult Primary Task* condition irrespective of Message Length. Likewise, Temporal workload significantly increased from (M = 1.428, SE = 0.266) for the *Easy Primary Task* condition to (M = 2.078, SE = 0.260) for the *Difficult Primary Task* condition. These data confirm that the primary task workload manipulation was partly successful.

## 3.3 Secondary Task Performance

Separate general linear models were used to determine differences for the time elapsed to acknowledge the message alert (*Acknowledgement Time*) and the time to send the final message (*Send Tme*). A Gender (Male, Female) x Primary Task Difficulty (Easy, Hard) x Message Length (1 Message, 3 Messages) ANOVA with repeated measures on the last two factors was conducted for both dependent variables. Table 3.5 presents means and standard errors for the three-way factor combinations for both dependent variables. The Gender x Primary Task Difficulty x Message Length for message Acknowledgment Time or message Send Time were not significant, $F$ (1, 17) = 1.168 and $F$ (1, 17) = 0.681, respectively. The following lower order interactions for message Send Time were also not significant: Task Difficulty x Message Length, $F$ (1, 17) = 2.049; Gender x Message Length, $F$ (1, 17) = 0.387. While the Task Difficulty x Message Length interaction was also not significant for message Acknowledgement Time, $F$ (1, 17) = 0.224, the Gender x Message Length interaction did emerge as significant, $F$ (1, 17) = 4.09, $p < .05$. Post hoc t-tests using Bonferonni corrections confirmed that females ($M$ = 32034.23 ms, $SE$ = 7008.87) took longer to complete and send the message following their acknowledgement that a message was available as compared to males ($M$ = 23934.73, $SE$ = 8218.66) for the Three message condition.

*Table 3.5. Means and standard errors for the secondary task dependent variables.*

| | | | Send Time | | Acknowledge Time | |
|---|---|---|---|---|---|---|
| **Gender** | **Primary Task** | **Message** | **Mean** | **SE** | **Mean** | **SE** |
| **Male** | **Easy** | **One** | 6961.16 | 733.96 | 5726.30 | 1536.52 |
| | | **Three** | 19916.76 | 1841.27 | 6047.86 | 1820.72 |
| | **Difficult** | **One** | 8887.34 | 1677.93 | 6116.52 | 7956.63 |
| | | **Three** | 27952.70 | 16222.03 | 9371.90 | 4477.45 |
| **Female** | **Easy** | **One** | 9654.89 | 625.92 | 7110.27 | 1310.35 |
| | | **Three** | 20371.96 | 1570.24 | 7087.91 | 1552.71 |
| | **Difficult** | **One** | 10233.84 | 1430.94 | 26523.46 | 6785.44 |
| | | **Three** | 43696.51 | 13834.19 | 18992.84 | 3818.38 |

Two additional main effects were further identified as significant. First, a main effect for Send Time was observed for Message, $F$ (1, 17) = 15.215, $p < .001$, indicating participants expectedly required more time to enter longer messages. On average participants required 8934.306 ms ($SE$ = 702.963) to enter one message and 27984.482 ms ($SE$ = 5400.717) to enter three messages. Second, Acknowledgement Time was observed to significantly vary with Primary Task Difficulty, $F$ (1, 17) = 6.584, $p < .05$. That is, participants were significantly slower to respond to the occurrence of a message alert during the Easy ($M$ = 6493.083, $SE$ = 862.763) compared to alerts occurring during the Difficult condition ($M$ = 15251.181, $SE$ = 3703.183). On the other hand, the average time participants required to send the message did not vary as a function of Primary Task Difficulty, $F$ (1, 17) = 2.252.

## 3.4 Heart Rate Variability

Separate general linear models were used to determine differences for the *Very Low, Low, High, and Very High* heart rate variability frequency components. A Gender (Male, Female) x Primary Task Difficulty (Easy, Hard) x Message Length (1 Message, 3 Messages) ANOVA with repeated measures on the last two factors was conducted for each dependent variable. The omnibus interaction for the Very Low, and High Frequency bands were not significant, $F$ (1, 21) = 0.710 and $F$ (1, 21) = 1.436, respectively. A strong linear trend was observed for the Very High HRV frequency band, $F$ (1, 21) = 3.191, $p$ = .08. Further, the three-way interaction for the Low frequency band was significant, $F$ (1, 21) = 4.667, $p < .05$.

Table 3.6 presents the means and standard errors for the interaction factor combinations. Select follow-up analyses indicated a trend between greater HRV in the Easy/One Message and Easy/Three Message condition compared to each of the other experimental conditions. However,

follow-up comparisons did not reveal any significant differences within the larger significant three –way interaction.

*Table 3.6. Means and standard errors for the heart rate variability dependent variables by factor combination.*

| | | | VLFB | | LFB | | HFB | | VHFB | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | **Primary Task** | **Message** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** |
| **Male** | **Easy** | **One** | 25.743 | 4.025 | 12.117 | 4.255 | 10.592 | 3.664 | 4.711 | 1.520 |
| | | **Three** | 33.240 | 6.921 | 18.374 | 6.053 | 9.965 | 2.948 | 6.624 | 2.284 |
| | **Difficult** | **One** | 20.054 | 2.248 | 6.395 | 1.124 | 5.275 | 1.286 | 5.249 | 1.801 |
| | | **Three** | 21.659 | 2.900 | 4.304 | 0.617 | 2.105 | 0.434 | 1.237 | 0.371 |
| **Female** | **Easy** | **One** | 22.023 | 3.530 | 8.382 | 3.732 | 3.598 | 3.214 | 0.766 | 1.333 |
| | | **Three** | 20.795 | 6.071 | 5.533 | 5.308 | 2.882 | 2.586 | 1.067 | 2.003 |
| | **Difficult** | **One** | 20.519 | 1.972 | 4.313 | 0.986 | 1.945 | 1.128 | 0.926 | 1.579 |
| | | **Three** | 19.829 | 2.543 | 4.331 | 0.542 | 1.969 | 0.381 | 1.092 | 0.325 |

Note: Values reported refer to power spectral density in $sec^{2/Hz}$.

In addition to the significant interaction, a main effect for Primary Task Difficulty was also observed for both the Low and High Frequency band components, $F$ (1, 21) = 4.170, $p < .05$ and $F$ (1, 21) = 5.663, $p < .05$. Participants occasioned significantly less variability for both of these spectral bands in the Difficult as compared to the Easy primary task condition (Low: $M$ = 4.836, $SE$ = 0.413 versus $M$ = 11.102, $SE$ = 3.198; $M$ = 2.824, $SE$ = 0.505 versus High: $M$ = 6.759, $SE$ = 2.091). The main effect for the Very Low, $F$ (1, 21) = 2.489, and the Very High, $F$ (1, 21) = 0.118, frequency components were not significant.

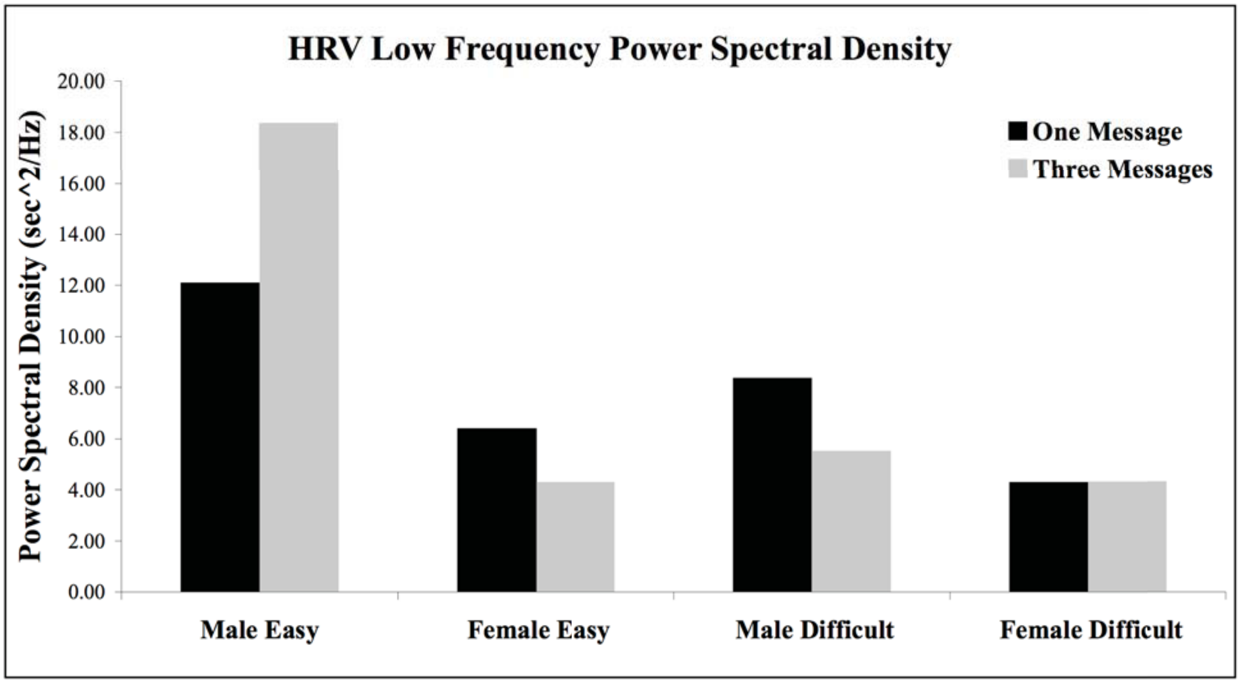


*Figure 3.1. Heart rate variability power spectral density for the low frequency range*

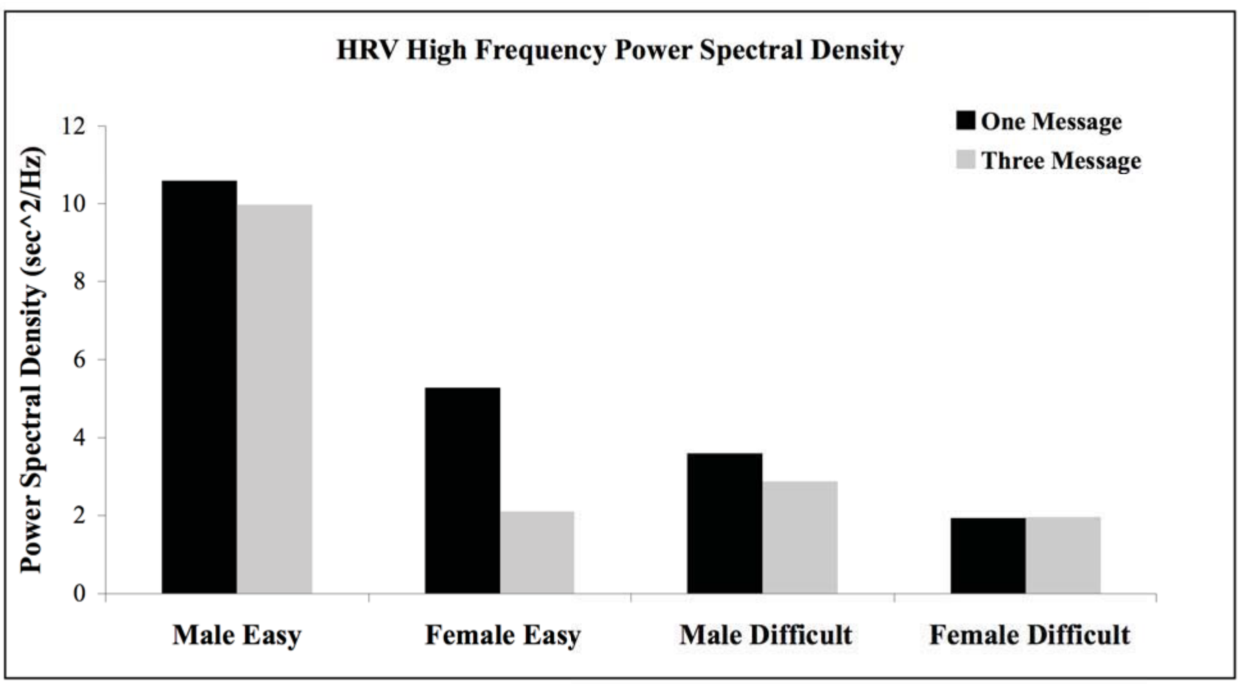


*Figure 3.2. Heart rate variability power spectral density for the high frequency range.*

### 3.4.1 Event-Related Potentials

Separate general linear models were used to determine differences for the *P3 Amplitude, P3 Latency, N1 Amplitude, and N1 Latency*. A Gender (Male, Female) x Primary Task Difficulty (Easy, Hard) x Message Length (1 Message, 3 Messages) ANOVA with repeated measures on the last two factors was conducted for each dependent variable. A significant three-way interaction for P3 Latency emerged, $F$ (1, 8) = 5.214, $p < .05$. However, follow-up analyses were inconclusive because of the low sample size in each of the factor cells. The omnibus three-way interactions for P3 Amplitude, N1 Latency, N1 Amplitude were not significant, $F$ (1, 8) = 0.642, $F$ (1, 8) = 0.216, $F$ (1, 8) = 0.216. Other lower order interaction and main effects were also not significant.

*Table 3.7. Means and standard errors for electrocortical dependent variables by factor combination.*

| | | | P3 Amplitude | | N1 Amplitude | | P3 Latency | | N1 Latency | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Gender** | **Primary Task** | **Message** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** |
| **Male** | **Easy** | **One** | 0.556 | 0.265 | -0.896 | 0.184 | 284.200 | 11.218 | 133.000 | 6.631 |
| | | **Three** | 0.972 | 0.408 | -0.593 | 0.312 | 319.800 | 15.365 | 124.000 | 5.990 |
| | **Difficult** | **One** | 0.896 | 0.336 | -0.724 | 0.429 | 314.400 | 14.025 | 120.400 | 3.593 |
| | | **Three** | 0.446 | 0.193 | -0.794 | 0.170 | 286.600 | 8.149 | 114.000 | 5.534 |
| **Female** | **Easy** | **One** | 0.890 | 0.265 | -1.019 | 0.184 | 322.200 | 11.216 | 132.800 | 6.631 |
| | | **Three** | 1.058 | 0.408 | -1.332 | 0.312 | 328.200 | 15.365 | 120.600 | 5.990 |
| | **Difficult** | **One** | 0.816 | 0.336 | -1.278 | 0.429 | 282.200 | 14.025 | 127.600 | 3.593 |
| | | **Three** | 0.602 | 0.193 | -1.630 | 0.170 | 314.800 | 8.149 | 115.400 | 5.534 |

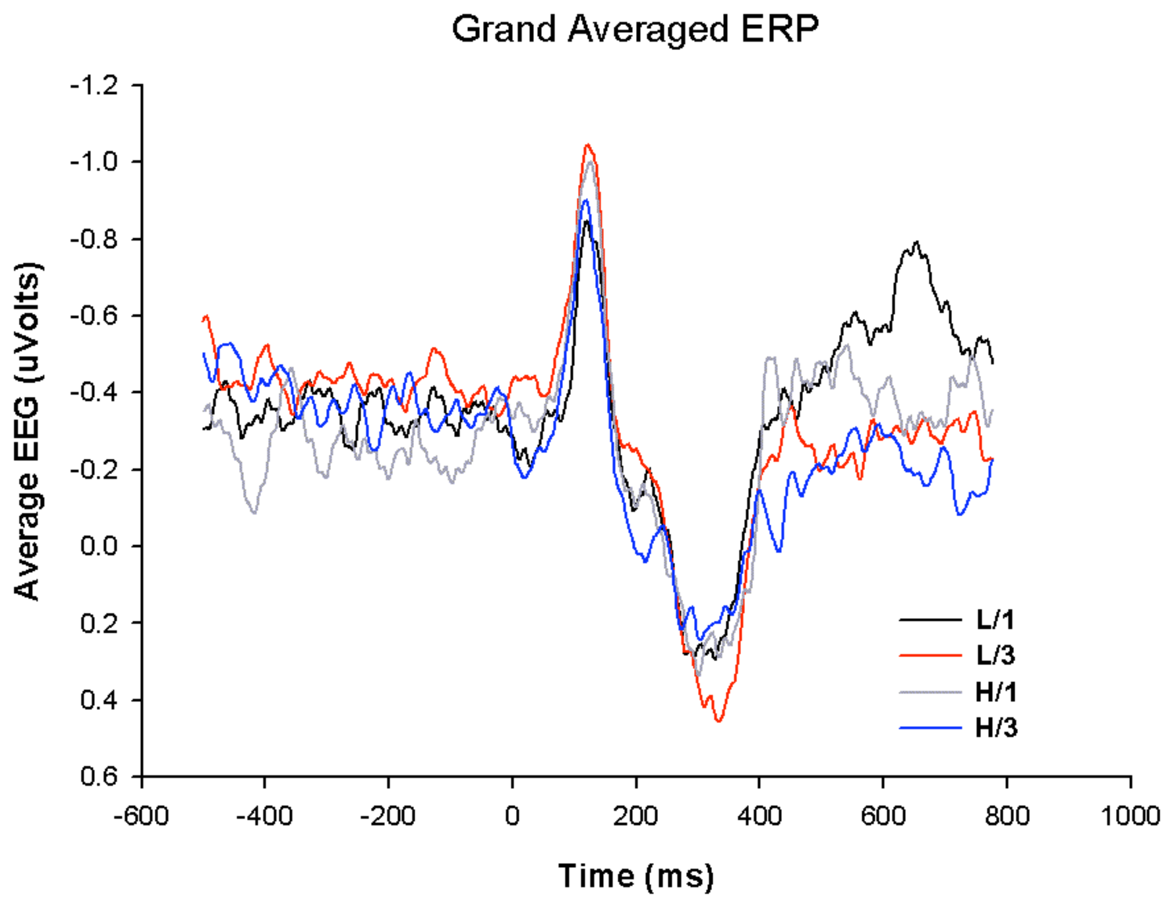


*Figure 3.3.* *Grand averaged ERP for all participants and cortical channels (P3, Pz, P4) and shown by Task and Messages factor combinations.*

## 4. Discussion

The purpose of this experiment was to examine operator workload demands when a messaging task is introduced as a secondary task requirement. The messaging task in this experiment required participants to replicate directional coordinate segments (i.e., 26 E, 120 N) in either single or triple message chunks at various intervals during a synthetic command and control primary task.

Generally speaking, participants exhibited both increased Mental and Temporal self-reported irrespective of Message Length, suggesting that the primary task workload manipulation was partially successful. A strong linear trend was also observed for manipulations of Message

Length, however this effect was not significant. The secondary task manipulation was furthermore revealing, with females taking on average longer to complete and send the message following their acknowledgement that a message was available as compared to males for the Three message condition. Participants were also significantly slower when responding to a message alert during given increased primary task difficulty. On the other hand, the average time participants required to send the message did not vary as a function of Primary Task Difficulty suggesting that participants tended not to time share between the primary and secondary task once the message entry began, but did adopt a hierarchical coping strategy by choosing only acknowledging the message alert when afforded by a event gap in the primary task. Participants were also observed to occasion significantly less variability for both of the Low and High frequency spectral bands in the Difficult as compared to the Easy primary task. However, follow-up analyses of these results were inconclusive. Despite a significant finding for P3 latency, findings related to ERP's were equally as inconclusive as those observed with HRV. That is, a distinct pattern of results failed to emerge given present task conditions. On the one hand, while physiological sensitivity is a major reason to include measures of psychophysiological function, it is conceivable that varying levels of expertise played a heavy role in obscuring a clear and unified physiological profile.

There are a number of limitations of the current study that should be addressed. First, as with many studies, a sample of convenience was used because ethnographic or other more ecological based evaluations where not possible. One then must question how the abilities of the operators in this study influenced the observed pattern of results. Moreover, the major question is how well these results describe how experts might react when confronted with the real world analog of this task? This challenge however is not a native problem to this study, but rather

represents a larger issue where samples of convenience are used in lieu of competent operators. Arguably, the various task requirements in this study were equivalent given the samples level of expertise with the experimental task relative to the task requirements to a real world operator. However, this is an assumption that is made for the purposes of this kind of research and one must be careful to consider the obtained results within this context.

In addition to the studies sample, some might argue that laboratory evaluation of mental workload does not permit robust assessment of true operator conditions in the real world. On the one hand, the experimental capacity to instantiate the substrata of real world stressors into a laboratory task are indeed challenging. For example, it is self-evident that replication of the task conditions during the first Gulf War to mimic the level of war fighter stress induced would be impractical. On the other hand, this study clearly observed task engagement and level of self-reported and physiological workload across task conditions. Therefore, it is reasonable to conclude that participant engagement in this study reflected a true snapshot of what may be experienced by more experienced operators, particularly where another novel task requirement (i.e., chat) is introduced into one's primary scope of responsibility.

During the Gulf War, as with modern chat applications, the lack of instant messaging *demand control* is a major problem that is not easily rectified. In normal voice communication, for example, it is common for one member, even when engaging in a long series of statements to wait or prompt for acknowledgement from the other conversation member. Silence for too long of period, in this particular case, may denote that the other party is not receiving or fully attentive of the incoming information. While there are exceptions, chat applications often are interacted with as tertiary to some primary task. If primary task requirements become to high, performance in the secondary task will decline. So, how then does one determine the other member's demand

without adding additional workload? What happens when a message is critical? How long do you wait for an acknowledgement before concluding that your message has not been conveyed? If a single operator is handling chat communication from multiple sources, how are such messages prioritized such that the operator can efficiently act on requests accordingly?

The standardization of a military specific chat grammar is another important consideration for fully realizing this technology. Many researchers have examined the emergence of localized chat grammars that evolve within user social networking communities. Laugh out loud "lol" is a common example. (see http://en.wikipedia.org/wiki/List_of_Internet_slang). The notion of chat grammar is to accelerate information exchange from the cumbersome act of keyboard entry. However, if chat is going to be used as a means of formal military communication, it is critical that each chat member clearly understand the information quickly and unambiguously. This is particularly important where multiple operators might perform the same job in different shifts but the shift operator needs to understand both the context and meaning of earlier exchanges. However, there are several strategies that may mitigate this problem such as chat certification for domain specific tokens (i.e., keywords) that operators would use within certain job functions.

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## 6. Appendix A

The complete IRB packet must be submitted by the 1st business day of the month for consideration at that monthly IRB meeting. Please see page 6 of this manual for detailed instructions on completing this form.

1. **Title of Project**: Collaborative Technologies and Their Effect on Operator Workload in $BMC^2$ Domains: A Multi-Modal Approach

**2. Principal Investigator(s):**

| | | | |
|---|---|---|---|
| Signature: | ____________________ | Signature: | ____________________ |
| Name: | **Aaron R. Duley** | Name: | ____________________ |
| | Mr./Ms./Mrs./Dr. (circle one) | | Mr./Ms./Mrs./Dr. (circle one) |
| Degree: | **Ph.D.** | Degree: | ____________________ |
| Title: | **Postdoctoral Researcher** | Title: | |
| Department: | Institute for Sim & Training | Department: | ____________________ |
| College: | ____________________ | College: | ____________________ |
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| Facsimile: | **(407) 823-5862** | Facsimile: | ____________________ |
| Home Telephone: | (407) 489-5836 | Home Telephone: | ____________________ |

**3. Supervisor:**

| | | | |
|---|---|---|---|
| Signature: | ____________________ | Degree: | ____________________ |
| Name: | **James Szalma** | Title: | ____________________ |
| | Mr./Ms./Mrs./Dr. (circle one) | Telephone: | ____________________ |
| Department: | Psychology | Facsimile: | ____________________ |
| College: | **Arts and Sciences** | E-Mail: | ____________________ |

**4. Dates of Proposed Project (cannot be retroactive):** From: 7/5/05 To: 7/5/06

**5. Source of Funding for the Project: (project title, agency, and account number):** United States Air Force

FA865005C6651

**6. Scientific Purpose of the Investigation:** Investigate human mental workload using collaborative technologies in battle management and control tasks.

**7. Describe the Research Methodology in Non-Technical Language: (the UCFIRB needs to know what will be done with or to the research participants)** The participants will engage in a military command and control tasks on a computer. Participants will also complete several questionnaires.

**8. Potential Benefits and Anticipated Risks. (Risks include physical, psychological, or economic harm). Describe the steps taken to protect participant**. The display used for the tasks in the proposed study is similar to graphic displays used in commercially available computer programs, which have no known negative long-term effects on participants. Application of the sensors to the body poses minimal problems. A sensor is applied 1) by first cleaning the skin by rubbing briskly with a tissue, 2) applying a jelly, and 3) attaching the sensors to the skin with a tape-like collar. Individuals with high sensitivity to cosmetics or creams, or extreme skin allergies may find that a short-lived redness at certain sites develops after the sensors are applied, although most people find the procedure harmless. The possibility of infection at any site where sensors are applied is non-existent in most cases, and minimal at most, as proper cleaning and sterilization procedures are implemented at all times. Participants will benefit from the proposed study by learning about physiological data collection methods, issues relevant to military command and control domains, and how the brain divides attention to multiple tasks.

**9. Describe how participants will be recruited, the number and age of the participants, and proposed compensation (if any):** Participants in each experiment will be recruited from the student population at UCF. They will range from 18 to 60. Compensation for participation will be extra course credit provided via Experimentrak. Particiapants will receive 1 credit point for each half hour of participation. If participants only complete part of the experiment, they will receive compensation for the amount time you have spent in the experiment rounded to the nearest half-hour interval.

**10. Describe the informed consent process: (include a copy of the informed consent document)** The experimenter will verbally describe the study to the participant, and the participant will read and sign the informed consent form. The experiment will not begin until the participant has read, had any questions answered, and signed the informed consent form.

**I approve this protocol for submission to the UCFIRB.**

________________________/_________ Department Chair/Director/ Date

## Introduction

This study addresses the need to better understand operator workload/performance issues in Battle Management Command and Control (BMC$^2$) domains. The project's primary aim will be to explicate workload/performance dissociations by mapping data derived from existing C$^2$ Simulated Training Environments (STE; e.g., Distributed Dynamic Decision-Making; DDD) with a multi-modal assessment protocol that will bridge both direct and indirect forms of inquiry. In this analysis, *the issue of individual operator workload associated with the integration of collaborative technologies (CT) into workflow operations will be of primary interest.*

A quintessential component of command and control environments are the unique and dynamic contingencies imposed upon the operator. Command and control (C$^2$) operators are often required to make rapid and important decisions in situations of scant and overwhelming intelligence. Thus, tools that can aid orchestration and management of information, or by the facilitation of information exchange via team coherence, have the potential to significantly improve mission effectiveness. However, it is also possible that such interventions will increase the workload on C$^2$ operators and thereby impair performance in stressful operational conditions. Analysis of the relation between performance and workload with respect to addition of new technologies is therefore critical for ensuring mission success.

Collaborative technologies intend to enhance operator and team efficiency by serving as a conduit for users to better share, organize, and process information. Integration of network-based tools such as chat, whiteboard, photo- and application- sharing, video- and audio- conferencing, and seamless file transfer capabilities, to cite a few examples, have the potential to significantly improve operator productivity, decision-making, problem-solving, and team situational awareness. Though novel CT are meant to replace outdated systems for information exchange, improve operator efficiency, or to simplify complex collaborative tasks, there are important questions to answer regarding the performance and workload effects of integrating network-based information sharing tools into contemporary BMC$^2$ operations.

To date, research evaluating the efficacy of various CT has indicated limited effectiveness

of these technologies for enhancing performance. For example, Navy operational commanders during Operation Iraqi Freedom reported that the amount of information generated by instant messaging (IM) became problematic because it became difficult to extract and synthesize (Caterinicchia, 2003). In a recent study, Cummings (2005) investigated the use of IM capabilities in a tactical Tomahawk simulation, finding that participants would persistently fixate on the IM window despite being instructed that the responding to message events was secondary to a primary task of monitoring and responding to missile retargeting. While CT will certainly have their place in network-centric warfare, it is crucial that these technologies be systematically evaluated for their impact on performance and workload.

The human brain has evolved in conditions where processing constraints have necessitated neural systems that seek to reduce the burden of a data-rich environment by filtering information through selective attention. The brain must process and organize the voluminous data collected through the sensory systems into a meaningful information array that affords coordination of timely response to novel stimulus contingencies appearing unpredictably in space and asynchronously in time. However, the systems that process this information are inherently limited in their capacities (Broadbent, 1958). These capacity limits are manifested in diverse environments *as the cognitive workload and stress associated with task performance*. To date, there has been limited theoretical or empirical research to articulate the factors that influence the complete link between performance and perceived workload. Given that different task domains produce different performance-workload relations, a central question emerges: *what factors drive subjective measures of workload and what information do these measures provide that are not intrinsic to performance measures?* Such relations provide only on single scalar link between multiple faces of performance.

## Method

### *Participants*

Participants will be selected from undergraduates enrolled in psychology courses or in the UCF community. There will be no inclusion or exclusion criteria except that participants must have normal or corrected to normal vision and have no known hearing impairments. Participation will be completely voluntary, and will not negatively affect students' grades in any way.

Students who choose to participate in this research effort will be compensated with extra course credit. To complete the study, we anticipate two one-hour sessions. The first session will consist mostly for training participants on the primary command and control task, while the second session will be dedicated to actual testing. Each session is not anticipated to exceed one hour and thirty minutes. The experiment will not begin until the participant has read and signed the informed consent (See Appendix A) and had any questions or concerns addressed. All individual information gathered during this study will be kept strictly confidential. Further, the information provided throughout participation in this study will be stored in such a way that it will not be connectable to people's names. Further, experimental data will be stored in such a way that there will be no way of linking people to data file(s), thus ensuring privacy. Informed consent forms will they be kept in a locked filing cabinet in a locked office AND separate from the data.

***Experimental Design***

The primary task in each experiment will require participants to engage in a synthetic task environment that mimics many of the characteristics common to command and control domains. The simulation software is called the Distributed Dynamic Decision-Making by Aptima. The software allows one to control icons which represent various battlefield assets such as tanks, planes, bases, etc. the goal of the software is for the participant to make strategic decisions such that they fulfill mission objectives (see Figure 1).

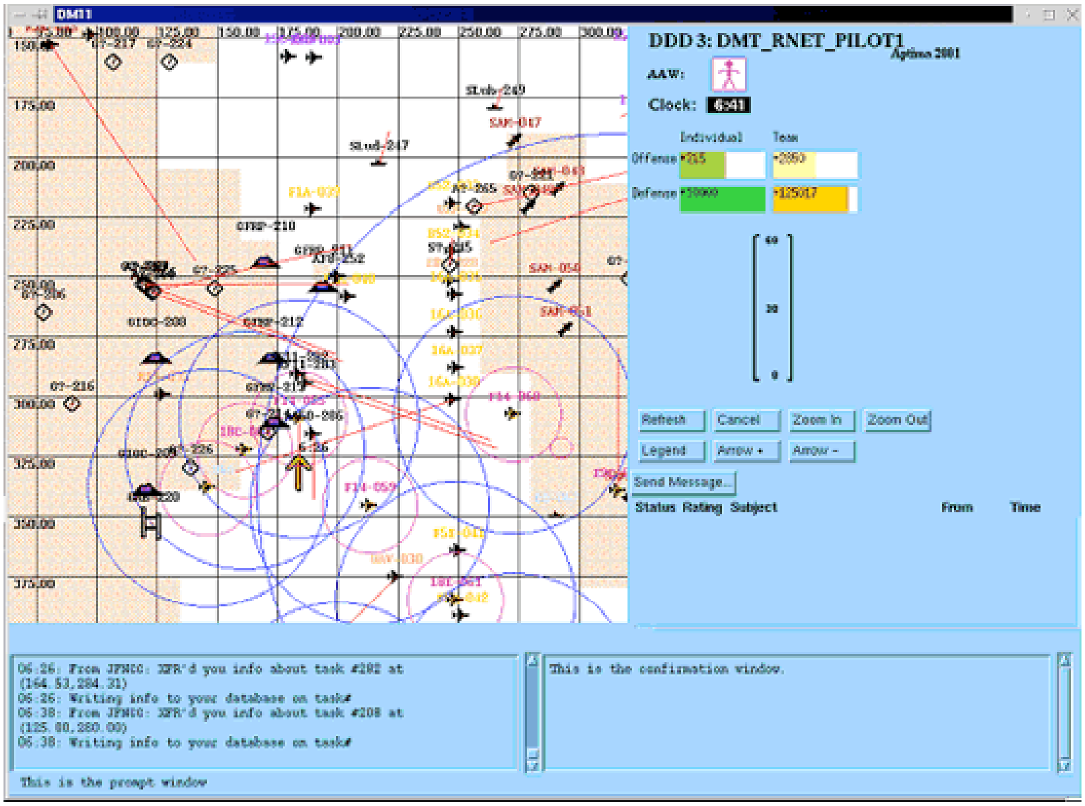



Figure 1. Primary Task Screenshot

The specific mission, in the proposed experiment, will require participants protect a base against attacks from enemy forces. A secondary task will require that participants respond to a tone that will occur at intermittent points during the primary task. Participants will be instructed to click a small button located on the screen when they hear this tone. Once a button is pressed, a chat window appears with latitude and longitude coordinates that the participant will be asked to replicate as quickly and as accurately as possible without compromising their responsibilities on the primary task. This paradigm, therefore, will allow us to assess the impact of instant messaging (collaborative technology) during a primary C2 task. We will assess behavioral data with respect to the response latency to press the button following the tone and to replicate the coordinates in addition to any input errors that may occur as the primary and secondary task collectively increase participant workload. During the experiment we will also monitor eye point of gaze data. This behavioral measure of attentional allocation will be helpful in determining how attention is allocated between the primary and secondary tasks. In addition to these behavioral measures, physiological markers of workload will also be collected in the form of

electrocortical potentials and electrocardiographic activity. This will require that participants wear small electrodes during the experiment. In addition to this instrumentation, the following questionnaires will also be administered:

***Measures of Workload and Mood*** – Perceived mental workload will been measured by the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), a well regarded instrument that gauges six dimensions of perceived workload on a scale of 0 to 100. In all experiments mood states will be measured using the Dundee State Questionnaire (DSQ), a multidimensional instrument for assessing transient states associated with mood, arousal and fatigue (Matthews et al., 1999; see Appendix C for pre- and post-versions of this questionnaire). This instrument has been shown to be sensitive in investigating the effects of task factors on operator mood state (Grier, et al., 2004; Helton, Dember, Warm, & Matthews, 1999; Matthews, et al., 1999; Szalma et al., 2004).

***Personality Measures*** – Trait and state anxiety will be measured using the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). The STAI assess trait feelings of emotionality as well as transient feelings of emotionality experienced during task performance. The Eysenck Personality Inventory (EPI) will also be administered. The EPI produces to personality scores of neurotiscm and introversion.

## Description of Experimental Protocol

After a brief verbal description of the experiment by the experimenter, participants will be presented with an informed consent form that explains their rights as participants, including the right to withdraw their participation at any time without penalty (See Appendix A for a copy of the informed consent form). The experiment orientation session will not begin until the participant has read, had any questions answered, and signed the informed consent form. All data sheets will be coded with a participant number to maintain confidentiality.

Following informed consent, participants will be asked to complete several of the above questionnaires followed by a presentation that will detail instructions for how to use the primary task. At the first session, any questions regarding the task objectives as well as the task itself will

be addressed. Once participants have completed this initial session they will be scheduled for an experimental session.

Once the participant arrives for the experimental session they will be greeted and then asked to play a practice session for the primary task, and any questions about how to use the task will be answered. Following this practice task (~ 15 minutes) the physiological instrumentation will be affixed and the eye tracker calibrated (~15 minutes). The participant will then engage in four task scenarios each approximately lasting 10 minutes. Upon completion of the task, participants will complete a computerized version of the NASA-TLX while the next scenario is loaded. A de-briefing form will be given to the participant at the end of the session.

***Potential Risks and Benefits***

The display used for the tasks in the proposed study is similar to graphic displays used in commercially available computer programs, which have no known negative long-term effects on participants. Application of the sensors to the body poses minimal problems. A sensor is applied 1) by first cleaning the skin by rubbing briskly with a tissue, 2) applying a jelly, and 3) attaching the sensors to the skin with a tape-like collar. Individuals with high sensitivity to cosmetics or creams, or extreme skin allergies may find that a short-lived redness at certain sites develops after the sensors are applied, although most people find the procedure harmless. The possibility of infection at any site where sensors are applied is non-existent in most cases, and minimal at most, as proper cleaning and sterilization procedures are implemented at all times.

# Informed Consent

The purpose of this study is to investigate variables that influence how people perform when using collaborative technologies in command and control environments.

**Anonymity:**

All individual information gathered during this study will be kept strictly confidential. Further, the information provided throughout participation in this study will be stored in such a way that it will not be connectable to people's names. Further, experimental data will be stored in such a way that there will be no way of linking people to data file(s), thus ensuring privacy.

**What is being asked:**

Participation will principally consist of filling out demographic and survey information forms and then performing PC-based tasks in another session. The tasks you perform on the computer will involve a game-like task that will require you to control battlefield assets and counteract attacks against those assets by enemy forces. During this primary task, you will be asked to respond to instant messages when prompted. The experimenter will explain how to do each task and the nature of the secondary task. After finishing each task, you will be asked to fill out a few questionnaires about your experiences during the session. The experiment will take approximately 1 hour and thirty minutes to complete, and will require you to return to the laboratory on one other occasion for approximately the same amount of time.

**Other concerns:**

The researchers agree to answer any questions that you may have at this time or at any time during the duration of the study. You do not have to answer any question that you do not wish to answer. If at anytime during the study you feel uncomfortable in any way, you can and should inform the researcher and the study will be terminated immediately with no penalty or loss of benefit.

Previous experience with computer-based tasks has shown that some participants may experience some level of physical discomfort, however, there is no major health risk involved as a result of participation in this study. However, if at any time you feel disoriented, sick, or nauseated, inform the researcher and the study will be terminated immediately without penalty or loss of benefit. Furthermore, the study poses no known psychological risks. Application of the sensors to the body poses minimal problems. A sensor is applied 1) by first cleaning the skin by rubbing briskly with a tissue, 2) applying a jelly, and 3) attaching the sensors to the skin with a tape-like collar. Individuals with high sensitivity to cosmetics or creams, or extreme skin allergies may find that a short-lived redness at certain sites develops after the sensors are applied, although most people find the procedure harmless. The possibility of infection at any site where sensors are applied is non-existent in most cases, and minimal at most, as proper cleaning and sterilization procedures are implemented at all times.

Participation is voluntary and you may terminate participation in the study at any time with no penalties by the researchers or the University and that the only benefit to you for participation is the payment you will receive for your participation. Compensation for your

participation will be extra course credit provided via Experimentrak. You will receive 1 credit point for each half hour of participation. If you only complete part of the experiment, you will receive compensation for the amount time you have spent in the experiment rounded to the nearest half-hour interval.

If you believe you have been injured during participation in this research project, you may file a claim with UCF Environmental Health & Safety, Risk and Insurance Office, P.O. Box 163500, Orlando, FL 32816-3500 (407) 823-6300. The University of Central Florida is an agency of the State of Florida for purposes of sovereign immunity and the university's and the state's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the university's and the state's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.

Information regarding your rights as a research volunteer may be obtained from:

**IRB Coordinator**
**Institutional Review Board (IRB)**
**University of Central Florida (UCF)**
**12201 Research Parkway, Suite 501**
**Orlando, Florida 32826-3246**
**Telephone: (407) 823-2901**

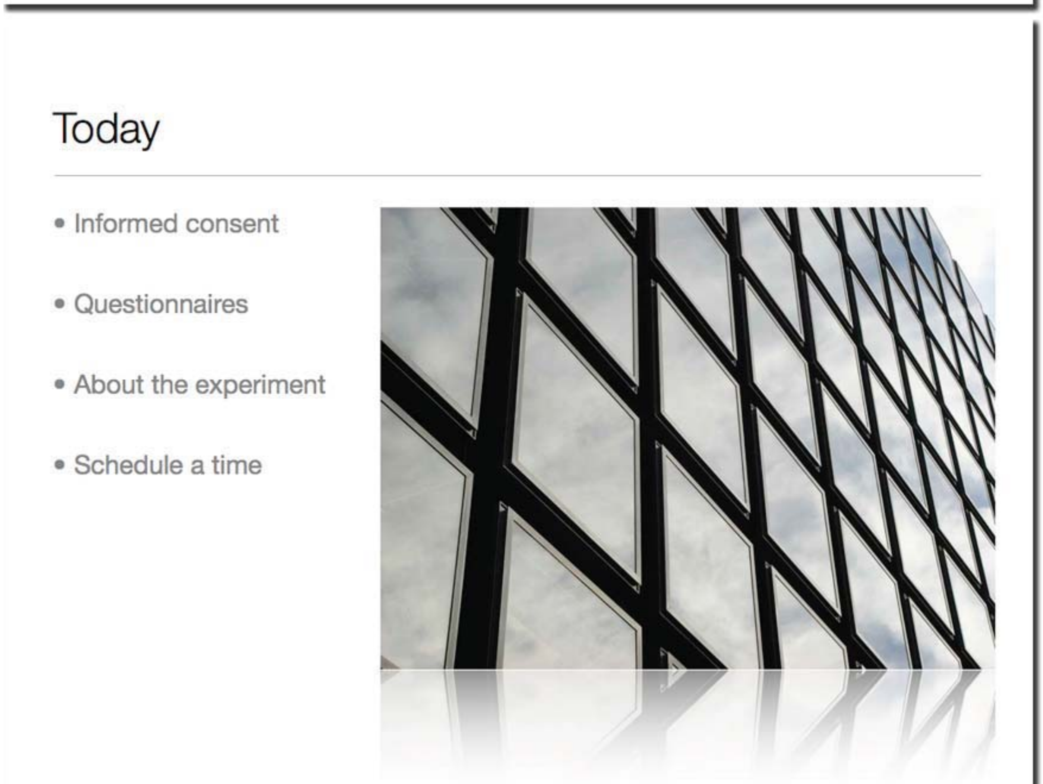
Questions about anything having to do with this study can be addressed to:
**Aaron R. Duley, Ph.D.**
**Institute for Simulation and Training**
**University of Central Florida**
**3100 Technology Parkway**
**Room 333**
**Orlando, FL 32826**
**Phone: (407)-823-1492**
**E-mail: aaronduley@gmail.com**

**I have read the procedure described above. I understand all points and agree to participate in the procedure and I have received a copy of this description. I further state and certify that I am at least 18 years of age.**

| | |
|---|---|
| ____________________________ | ____________________________ |
| **Signature of Participant** | **Signature of Researcher** |
| ____________________________ | ____________________________ |
| **Date** | **Date** |

# 7. Appendix B


Collaborative Technologies in BMC2 Study
Drs. Aaron R. Duley, James Szalma, P. A. Hancock
Minds in Technology, Machines in Thought Laboratory
Institute for Simulation and Training
University of Central Florida
Research sponsored by the United States Air Force in collaboration with the Air Force Research Laboratory. Special thanks to Dr. Todd Nelson, Robert Bolia, Brent Miller, Dr. Benjamin Knott


Today
• Informed consent
• Questionnaires
• About the experiment
• Schedule a time

## Informed Consent

Please take a few minutes to read and sign the informed consent form

If you have any question feel free to ask the experimenter

## Questionnaires

- Please take a few minutes to complete the questionnaires
- Do not put your name on any of the questionnaires
- Please ask the experimenter if you have any questions

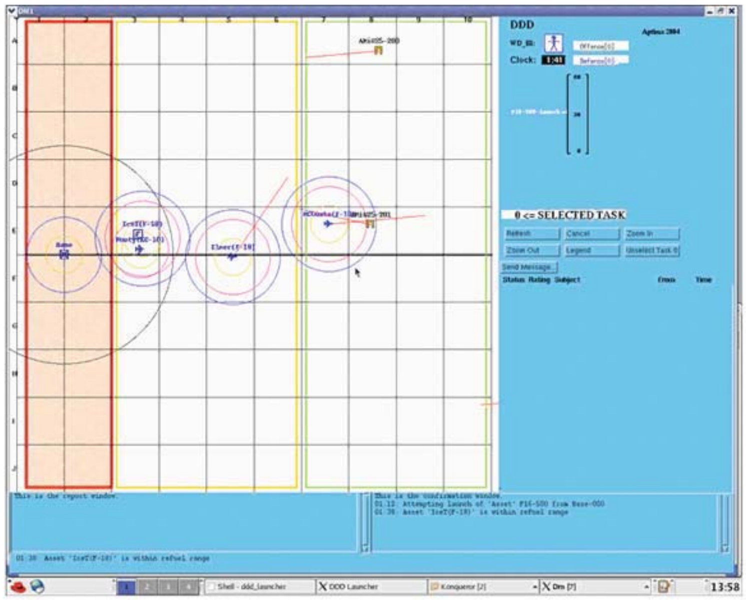
## About The Experiment

- You will be playing the role of a weapons director and strike operator in a command and control scenario
- The Tanker Scenario is a simulated air battle management command and control task developed with guidance from subject matter experts in conjunction with the Air Force Research Laboratory
- Operators communicate and coordinate to intercept and attack enemy targets, rearm and refuel friendly fighters with airborne tankers.

## Testbed

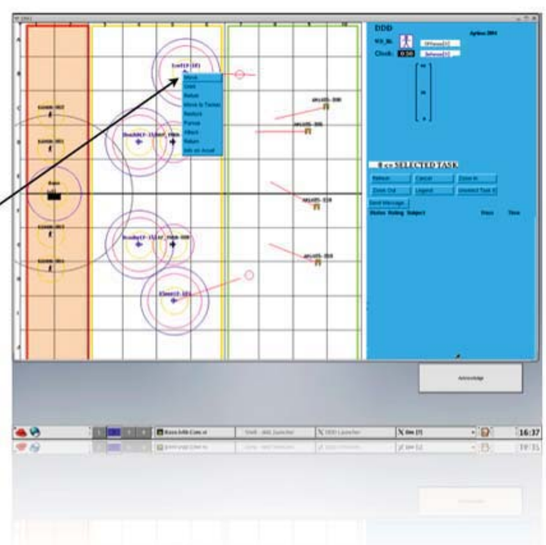
- The Dynamic Distributed Decision-Making Testbed (DDD) by Aptima, Inc.
- You own and control color-coded fighters, tankers, bases, etc.
- Coordinated attack and defense
- Protect friendly assets, eliminate enemy threats

# Testbed Example



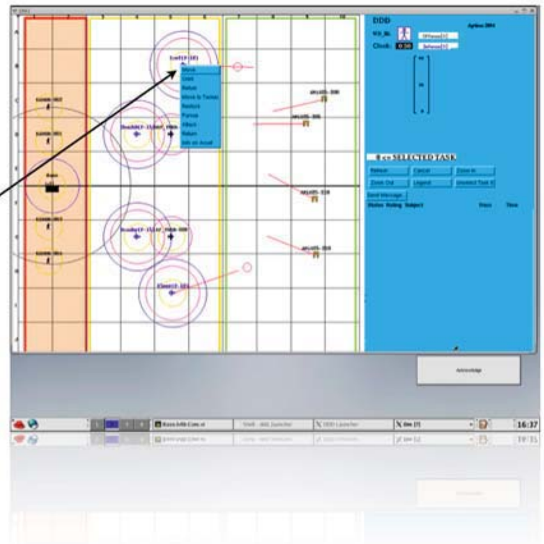

# Using DDD - Asset Menu

- The majority of commands will be issued by Right-Clicking on a given asset

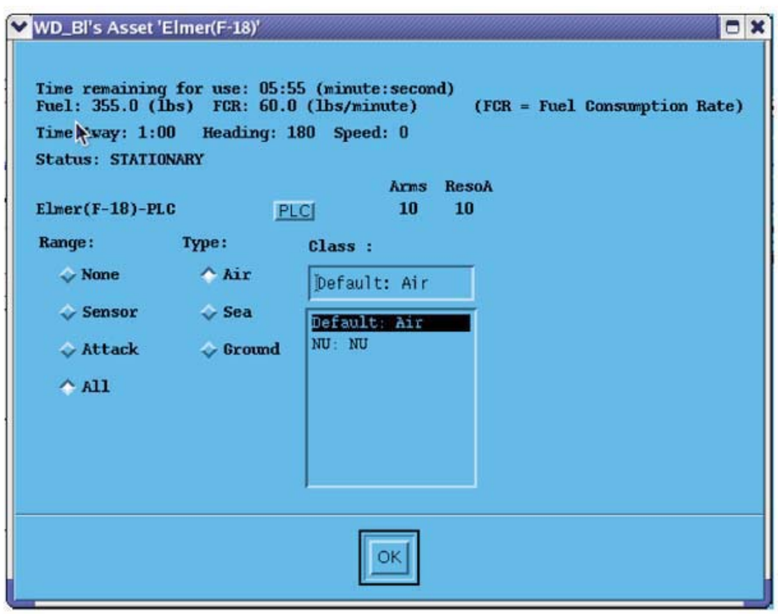


## Using DDD - Asset Information

- To get information about an asset:
  1. Right-Click on the asset
  2. Select 'Info on Asset' from the Menu

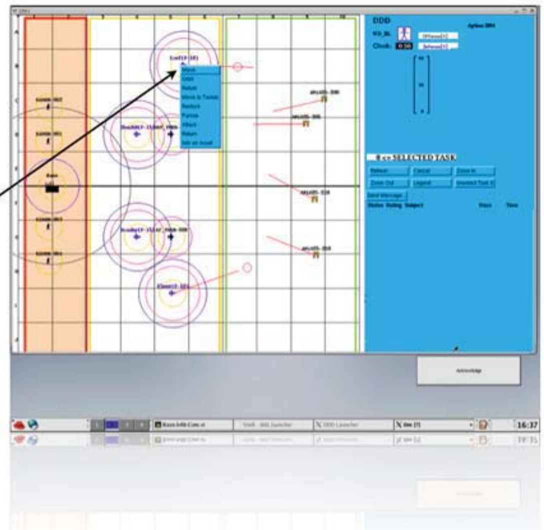



## Using DDD - Asset Information Dialog



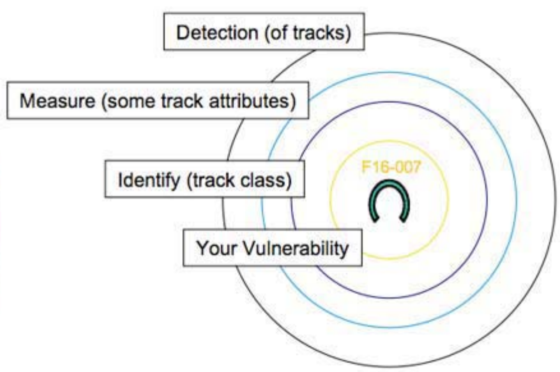
# Using DDD - Orbiting Assets

- To have an asset orbit:
  1. Right-Click on the asset
  2. Select ‘Orbit’ from the Menu



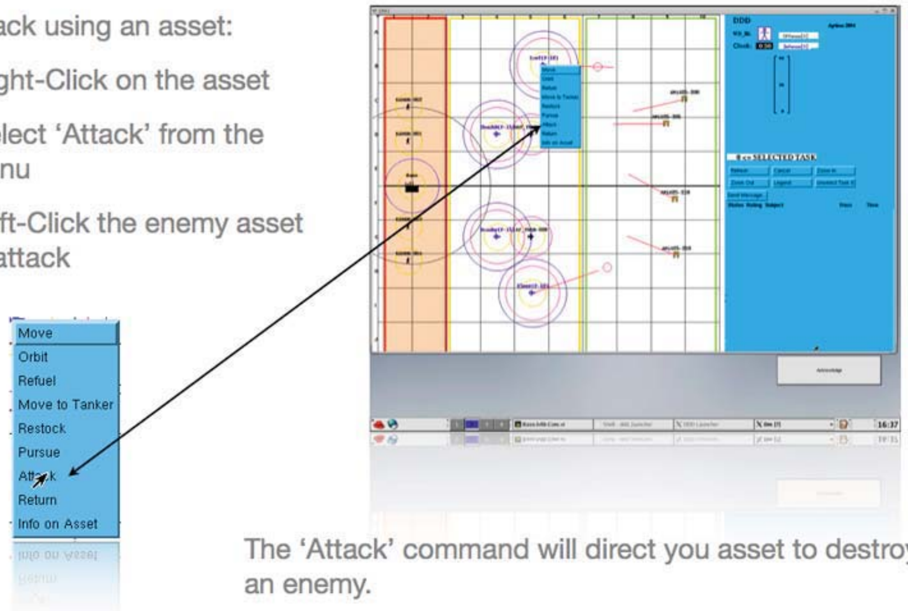

The ‘Orbit’ command will place a moveable asset into a stationary position.

# Using DDD - Rings

# Using DDD - Attacking

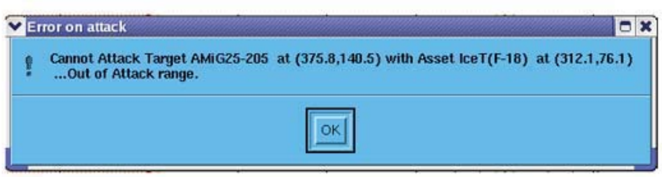
- To attack using an asset:
  1. Right-Click on the asset
  2. Select 'Attack' from the Menu
  3. Left-Click the enemy asset to attack




The 'Attack' command will direct you asset to destroy an enemy.

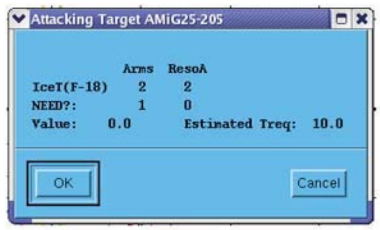
# Using DDD - Attacking

- Attack errors

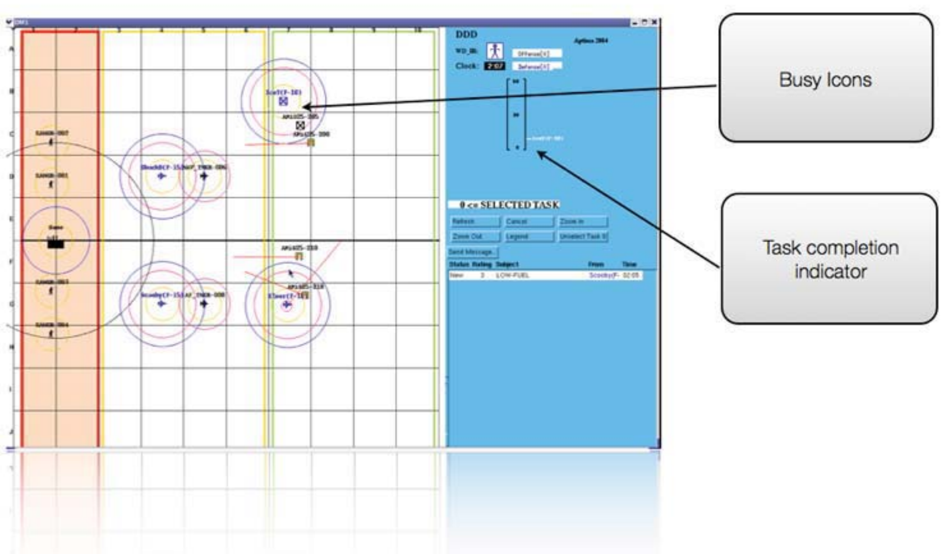


# Using DDD - Attack Confirmation

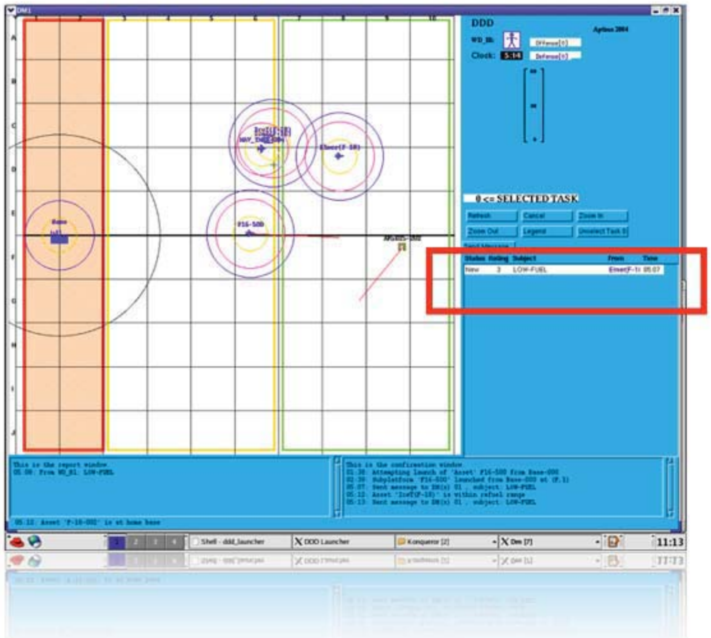
- Attack confirmation




# Using DDD - Attacking

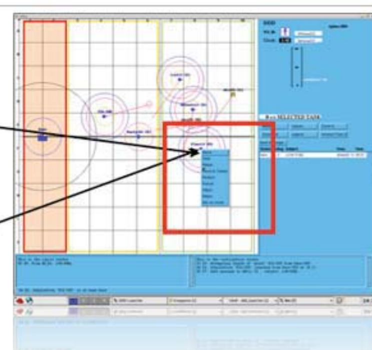


# Using DDD - Refueling

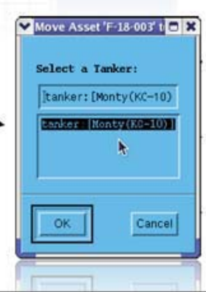


# Using DDD - Move To a Tanker

1. Right-Click on the Asset



2. Select ‘Move to Tanker’ from the Menu

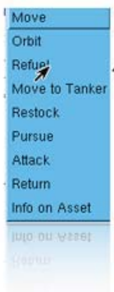



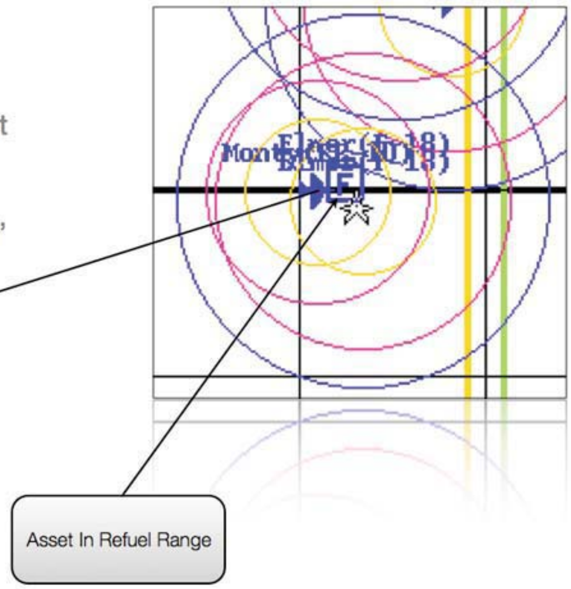

3. Select Tanker from Dialog > Click OK

# Using DDD - Refueling

- To refuel an asset when in Tanker Range:

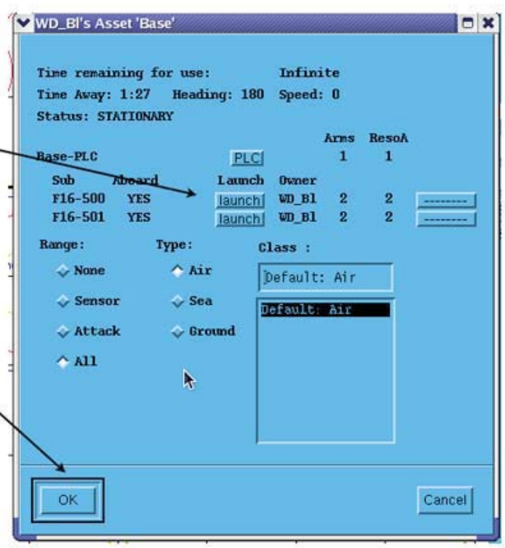
1. Right-Click on the tanker asset
2. Select 'Refuel' from the Menu
3. Place 'Star Cursor' over the 'F' and Left-Click




# Using DDD - Launching an Aircraft

1. Right-Click on the Base Icon
2. Click Launch
3. Click OK

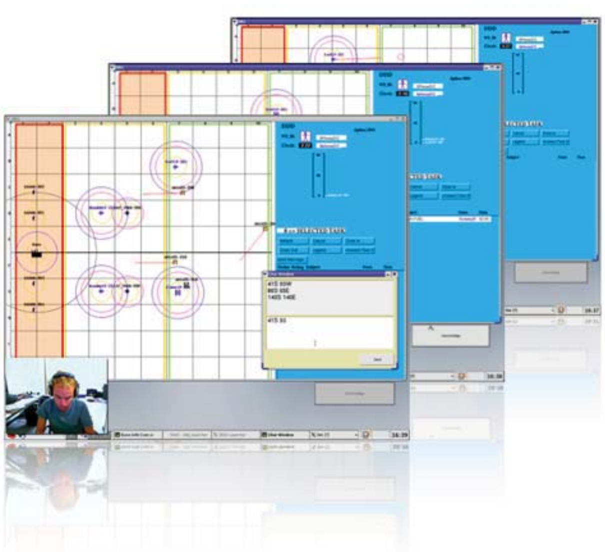


## Your function

- As Weapons Director (WD), you will run air defense operations by coordinating your assets while acting on incoming information from you tactical display

- WDs have global picture of the airspace on their tactical displays that is provided by an Airborne Warning and Control System (AWACS)

## Secondary Task



- Tone indicates new message

- Click 'Acknowledge' Button as quickly as possible without compromising your primary mission objectives

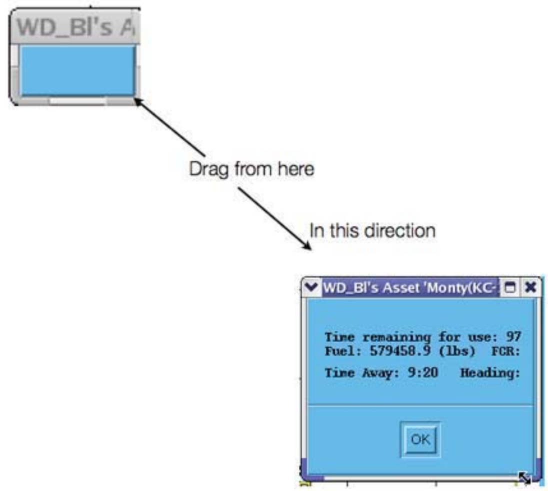
- This will launch the chat window

- Relay chat text (latitude and longitude Coordinates) as quickly and as accurately as possible

- Click 'Send' when done

# Task Scenario - Notes

- Refuel at the Base only in an emergency (requires more time)
- Resolving Window Errors - Move cursor to bottom-right of window and drag right and down




# Assets

KC-10 Refuel Tanker

F-18 Hornet: Strike fighter

## Task Scenario - Priorities

- Destroy as many hostile aircraft as quickly as possible.
- Do not allow hostile aircraft to enter friendly territory (Yellow and Red Zones ).
- Protect the Air Base
- Protect high value air assets: AWACS, Tanker
- Keep as many fighters airborne for as long as possible.

Mig-25

## Workload

- See Handout

## Using DDD - Questions

- Please feel free to ask any questions about how to use the task
- You will get a chance to run through a practice scenario before the prior to the actual experiment

## Sign-Up

- Please take a few minutes to complete a time to participate
- You will be credited in Experimentrak once you complete the testing session
  - PLEASE NOTE!!!!
    If you cannot make it to your scheduled time, call 407-823-1492 to reschedule ASAP